



Arnold Schwarzenegger
Governor

CERTS MICROGRID LABORATORY TEST BED

CERTS Microgrid Test Plan

APPENDIX B

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
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CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

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DTC Registered Procedure CERTS Microgrid Test Plan



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Revision #	Date	Revision Description
0	01/24/07	Original

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Revision #	Date	Revision Description
0	02/23/07	Original

Team Members and Roles

Name	Group	Primary Roles
Kevin P. Loving	DTC Operations	Test Site Coordinator
Dave A. Klapp	DTC Operations	Project & Test Engineer #1
Galen W. Perry	DTC Operations-Contractor	Test Operator/Technician #1
H. T. Vollkommer	Consultant-Contractor	Technical Support Consultant
John Stevens	Sandia National Lab.	CERTS Microgrid Test Team
Robert Lasseter	University of Wisconsin	CERTS Microgrid Test Team
Ed Linton	Northern Power Systems	CERTS Microgrid Test Team
Jean Roy	TECOGEN, Inc.	CERTS Microgrid Test Team

1.0 Purpose, References, Definitions

- 1.1 The purpose of this document is to establish procedures for testing of the CERTS Microgrid Test Bed, located at the Walnut Test Site near Columbus, Ohio. This Test Site is part of AEP's Dolan Technology Center (DTC) campus. The CERTS Microgrid Test Bed (referred to as "Microgrid") is connected on the load side of the 2000 ampere safety breaker of Test Cell #1, identified as CB1 in the single line diagram, CERTEQUIP-J01-001, dated March 24, 2006, and located in Appendix A.
- 1.2 Procedures necessary to perform tests on the Microgrid require:
 - 1.2.1 Walnut Test Site specifically adapted "DTC Clearance Permit System" procedures to facilitate on site testing of CERTS Microgrid Test Bed.
 - 1.2.2 Verification that the equipment is properly installed and wired in accordance with Northern Power System (NPS) and TECOGEN wiring prints, the controls operate as designed, protective equipment is installed and each piece of equipment is ready to be placed in service.
 - 1.2.3 On-line verification of voltages, phase rotations, control operations, and communications.
- 1.3 Pre-energizing tests of electrical components shall be performed to verify that no short-circuits exist or possible faulty equipment will be energized.

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- 1.4 The Microgrid shall be considered commissioned and available for use only after all the requirements identified in the NPS document, titled CERTS Test Bed, CERTEQUIP-T06-001-X9, Site Commissioning Plan, have been met.
- 1.5 References documents:
 - 1.5.1 DTC Standard Operating Procedures
 - 1.5.1.1 SOP – DTC Clearance Permit System, 204-DTC-05
 - 1.5.1.2 SOP – Barricades, Barriers and Guards, 204-DTC-11
 - 1.5.1.3 SOP – Personal Protective Equipment, 204-DTC-32
 - 1.5.1.4 SOP – DTC Parent SOP for Primary Distribution Switching, 204-DTC-50.0
 - 1.5.1.5 SOP – Sub-Procedure Primary Distribution Switching – Walnut Test Site, 204-DTC-50.08
 - 1.5.1.6 SOP – Job Safety Briefing, 204-DTC-70
 - 1.5.2 AEP Safety Manual
 - 1.5.2.1 Section 1.00 “General Safety”
 - 1.5.2.2 Section 6.00 “Basic Electrical Safety, clauses 6.01, 6.02, 6.04, 6.05, and 6.16.
 - 1.5.3 NFPA 70: “National Electric Code 2005”
 - 1.5.4 OSHA 1910.269 Electric Power Generation, Transmission and Distribution: Electrical Protective Equipment
 - 1.5.4.1 Subpart o – Testing and Test Facilities
 - 1.5.4.2 Subpart v – Power Generation
 - 1.5.5 Northern Power Systems (NPS) Documents – CERTS Test Bed
 - 1.5.5.1 CERTEQUIP-J01-001, Single Line Diagram
 - 1.5.5.2 CERTEQUIP-J06-001, Top Level Schematic
 - 1.5.5.3 CERTEQUIP-B02-001, General Arrangement
 - 1.5.5.4 CERTEQUIP-J06-003, Load Bank Schematic
 - 1.5.5.5 CERTEQUIP-J14-001, Grounding and Neutral Schematic
 - 1.5.5.6 CERTEQUIP-T06-001, Site Commissioning Plan
 - 1.5.5.7 CERTEQUIP-Y01-001, DAS Manual – LabView
 - 1.5.5.8 CERTEQUIP-Y01-002, EMS Manual
 - 1.5.5.9 CERTEQUIP-Y01-003, DAS Manual – Ion Meter
 - 1.5.5.10 CERTEQUIP-Y01-004, DAS & EMS System Overview

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1.5.5.11 CERTEQUIP-C16-001, Protection Document

1.6 Definitions

1.6.1 Walnut Test Site Issuing Authority Designee

- 1.6.1.1 A Designee assigned by the “DTC Issuing Authority” who will temporarily serve as the Walnut Test Site Issuing Authority Designee for this registered procedure.
- 1.6.1.2 Shall not be the Permit Holder for the CERTS Microgrid Test Bed or any part of this procedure or related equipment.
- 1.6.1.3 Is restricted to the CERTS Microgrid Test Bed and the switching of the Walnut Test Site 2000 ampere Station Safety Breaker, CB1.

1.6.2 CERTS Microgrid Test Bed – Test bed consisting of the Northern Power System (NPS) and TECOGEN equipment located at the Walnut Test Site. The boundary between the CERTS Microgrid Test Bed and AEP Grid is at the delta-wye transformer (T11) connected to the terminal box of the Walnut Test Site Station Safety Breaker CB1. Note, between T11 transformer and the CERTS Test Bed Safety Breaker (CB12) is a selectable High/Low in-series inductive impedance cabinet (L11).

1.6.3 Lockout/Tagout Log – A log listing the date and time of the Lock / Tag “in” and “out” operation of a designated disconnect device or circuit breaker that shall be tagged and locked out for a particular test sequence and test change.

1.6.4 Electrical One-Line Status Board – A cork bulletin board with the CERTS Microgrid Test Bed electrical one-line overlaid on the corkboard.

1.6.5 Red Pin – A red bulletin board pushpin, which designates location and a visual Red Clearance Permit Tag presence.

1.6.6 Lockout Lock Board – A board with five (5) green locks to be used for each lockout/tagout procedure. Each lock shall have a designated breaker or disconnect device and the board shall reflect labeling to this effect.

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- 1.6.7 Walnut Circuit Breaker Program – AEP created software to control the Walnut Test Site Recloser and Station Safety Breakers. This software is found on the Walnut Test Site Computer in the test trailer.

2.0 Responsibilities

Scheduling:	Test Site Coordinator
Parameter Specifications:	Project Engineer, Technical Support Consultant, CERTS Microgrid Test Team
Setup:	Test Engineer #1 & Test Operator/Technician #1 (Alternate: Technical Support Consultant)
Execution:	Test Engineer #1 & Test Operator/Technician #1 (Alternate: Technical Support Consultant)
Report:	Project Engineer, Technical Support Consultant, and CERTS Microgrid Test Team
Analysis:	Project Engineer, Technical Support Consultant, CERTS Microgrid Test Team
Approval:	Sponsor, CERTS Microgrid Test Team

2.1 Team Members

- 2.1.1 Team members shall comply with DTC operating procedures, as required by this registered procedure.
- 2.1.2 At least two people shall be on-site during test(s) and either Test Engineer #1 or Technical Support Consultant shall be on-site and in charge during the test(s). Test Engineer #1, Test Operator/Technician #1 and Technical Support Consultant, must be trained and qualified in the operation of both the DAS (Data Acquisition System) and EMS (Energy Management System) equipment, familiar with the test plan and emergency shutdown procedures, and has the most immediate control of the hazard-producing devices that is practical.
- 2.1.3 During a test event, the test shall be initiated and performed from the Control Trailer with “NO” humans physically located in the Microgrid Test Bed area or on the East, South or West sides of the Gen-set Enclosure during the test.
- 2.1.4 In preparation of and/or prior to performing a test event, one person may enter the Microgrid Test Bed with power enclosure doors in the Test Bed “latched” with no energized equipment

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terminals exposed or in contact with people. The second person on-site will be in the Control Trailer and situated such that he/she can view the test area and available to perform an immediate Emergency Shutdown Procedure.

2.1.5 The Test Engineer #1 or Technical Support Consultant shall be in the Control Trailer and situated such that he/she can view the test area, while the Test Operator/Technician #1 is performing the test(s). If an unsafe condition arises while the test area is energized, the Test Operator/Technician #1 shall be directed to perform an immediate Emergency Shutdown Procedure.

2.1.6 The Test Site Coordinator shall ensure that the required qualifications of all participants are met, including training cited in Section 3.0 of this Procedure.

2.1.7 The Test Site Coordinator shall be responsible for approving this procedure and any revisions.

2.2 Walnut Test Site Issuing Authority Designee

2.2.1 Shall comply with the DTC Clearance Permit System or the "CERTS Microgrid Test Bed Lockout/Tagout" procedure, cited in Section 4.0.

2.2.2 Shall place all tags, lockout devices and/or grounds associated with the CERTS Microgrid Test Bed.

2.2.3 Shall use AEP System safety procedures, PPE, and approved tools when isolating equipment and/or placing grounds for the CERTS Microgrid Test Bed.

2.2.4 Shall be knowledgeable about the CERTS Microgrid Test Bed and other systems distributing hazardous energy.

2.2.5 Shall not be a Clearance Permit holder for the CERTS Microgrid Test Bed. This ensures that at least two independent judgments are involved in deciding that the Clearance Permit provides a safe arrangement of devices and that the tags are properly placed.

2.2.6 Is responsible for addressing any observed non-compliance issues.

3.0 Training – Team Members

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- 3.1 The skills necessary to distinguish exposed high voltage/energy parts of the test equipment.
- 3.2 Basic Electrical Safety practices of the AEP Safety Manual shall be followed with Section 6.02 being the guiding principle and minimum approach distances specified in Section 6.03.
- 3.3 The proper use of personal protective equipment and insulated tools when working on or near exposed energized equipment.
- 3.4 The proper use of barricades, barriers or guards.
- 3.5 The proper operation of associated test equipment, based on the manufacturer's operator's manual, and of the DAS and EMS computer-based operating systems.

4.0 Procedure – CERTS Microgrid Test Bed Lockout/Tagout

- 4.1 The CERTS Microgrid Test Bed Lockout/Tagout procedure is designed to provide the same level of safety afforded by the DTC Clearance Permit system with less implementation overhead. Because of this, it can ONLY be applied under a limited set of applications, described as follows:
 - 4.1.1 To make adjustments of Fault/Overload breaker connections;
or
 - 4.1.2 To make adjustments to the weakening grid inductor in Cabinet L11.
- 4.2 These are the ONLY two reasons that the CERTS Microgrid Test Bed Lockout/Tagout procedure may be used. Any other application requiring the lockout/tagout of hazardous energy equipment will default back to the DTC Clearance Permit Procedure.
- 4.3 The Walnut Test Site Issuing Authority Designee shall:
 - 4.3.1 Issue a "Microgrid Clearance Permit" for the CERTS Microgrid Test Bed prior to testing and advance the permit to a "Permission to Test Operate" status.
 - 4.3.2 Assign this Clearance Permit to the Walnut Test Site Station Safety Breaker CB1, the Microgrid Main Breaker (CB12), the three Fused Disconnects on Gen-sets A1, B1 and A2.
 - 4.3.3 Be responsible for Lockout/Tagout of Walnut Test Site Station Safety Breaker (CB1), the Microgrid Main Breaker (CB12), the three Fused Disconnects on Gen-sets A1, B1 and A2, as required in these procedures.

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- 4.3.4 Verify that all tags and lockout devices are properly installed at the designated locations prior to a test.
- 4.3.5 Assure a “Job Safety Briefing” (JSB) has taken place prior to each test.
- 4.4 Walnut Test Site Issuing Authority Designee and Team Members shall independently confirm that the test configuration provides the protection required for the procedures to be undertaken.
- 4.5 A re-useable Microgrid Clearance Permit Tag shall be assigned to each circuit breaker and disconnect device that requires lockout/tagout for a particular test sequence.
- 4.6 Lockout Devices
 - 4.6.1 In addition to the tag types allowed by “AEP Fossil and Hydro Generation Clearance Permit System”, keyed padlocks will be placed in combination with each red tag placed on a device that is capable of being locked out, in accordance with the AEP Control of Hazardous Energy Policy.
 - 4.6.2 A green keyed-alike padlock shall be used as the default lockout device for the CERTS Microgrid Test Bed.
 - 4.6.3 Keys for the green keyed-alike padlocks shall be located:
 - 4.6.3.1 One key provided to the Issuing Authority.
 - 4.6.3.2 One key provided to the Walnut Test Site Issuing Authority Designee.
 - 4.6.3.3 Spare keys will be secured in the DTC key safe
- 4.7 Each time a CERTS Microgrid Test Bed Lockout/Tagout is required, the Walnut Test Site Issuing Authority Designee shall isolate the CERTS Microgrid Test Bed from the utility as follows:
 - 4.7.1 Remotely “Shutdown” all Gen-sets (i.e., A1, B1 & A2).
 - 4.7.2 Remotely “Trip” the Station Safety Breaker CB1, using the Walnut Circuit Breaker Program found on the Walnut Test Site Computer in the Control Trailer.
 - 4.7.3 Verify that no voltage exists on the Microgrid Test Bed, using the DAS meter readouts.

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- 4.7.4 Lockout/Tagout the Station Safety Breaker CB1, using the designated green lock.
- 4.7.5 Manually “Trip” circuit breaker CB12 to the CERTS Microgrid Test Bed.
- 4.7.6 Lockout/Tagout the CERTS Microgrid Test Bed circuit breaker CB12, using the designated green lock.
- 4.7.7 Open the Fused Disconnects on Gen-sets A1, B1 and A2.
- 4.7.8 Lockout/Tagout the Fused Disconnects to Gen-sets A1, B1 and A2, using the designated green locks.
- 4.7.9 The area (i.e., within/near cabinets) where work is to be performed shall then be checked with a voltage detector to confirm that hazardous potential has been removed.
- 4.7.10 Using the proper PPE, an approximately sized grounding conductor shall be connected between the electrical bus and ground, as close to the work area as reasonably feasible.
- 4.7.11 The Lockout/Tagout Log is in Appendix B and shall be completed, reflecting completion of the Lockout/Tagout procedure. The horizontal axis includes the breakers and disconnects, while the vertical axis includes the date, time and specific test described in this procedure document.
- 4.7.12 The work requiring this Logout/Tagout procedure may now be completed with the Red Clearance Permit Tag pins positioned on the Electrical One-Line Status Board to inform others of site status.
- 4.7.13 Perform these steps in reverse order. Then:
 - 4.7.13.1 Check to verify all grounds have been removed before energizing;
 - 4.7.13.2 Re-energize the CERTS Microgrid Test Bed; and
 - 4.7.13.3 Verify the proper nominal voltages in Meter 1.

4.8 CERTS Microgrid Test Bed-Test Log

- 4.8.1 A list of test events shall be organized in a logical sequence to complete all tests involving energizing work progressing from the utility source and Gen-sets to the last piece of equipment.

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- 4.8.2 Appendix C lists the “CERTS Microgrid Test Bed-Test Log” to be completed.
- 4.8.3 A single copy of Appendix C shall be printed out, initialed by the Test Engineer #1 performing the test or Technical Support Consultant, and dated.
- 4.8.4 Once Appendix C is completed, the appendix shall be attached to this document and stored in an electronic file.
- 4.8.5 All Team Members involved with the actual test shall acknowledge to the Test Engineer #1 or designated person that they are “Ready to go”.
- 4.8.6 Test Engineer #1 or designated person shall verify that the front gate to the Walnut Test Site is “Closed”, not locked, with an audible alarm in operation.
- 4.8.7 Test Engineer #1 or designated person shall then start the visual alarms.
- 4.8.8 Test Engineer #1 or designated person shall notify the Team Members “The test is about to begin”.

5.0 Procedure - General

- 5.1 Prior to testing each day, the person in charge during the planned test(s) or his designee shall perform a JSB, and the barricades and test setup shall be inspected for safety and compliance.
- 5.2 Alarms – Visual & Audible
 - 5.2.1 These alarms shall warn persons that energized testing is being performed in the Microgrid Test Bed area.
 - 5.2.2 Visual alarm, consisting of a portable red flashing light, shall be located between the Control Trailer and Gen-set Enclosure (i.e., North side of Enclosure between the coolant system structure and natural gas lines into the Enclosure).
 - 5.2.3 Audible alarm, consisting of a portable buzzer, shall be located at the front gate of the Walnut Test Site with the fence gate “Closed”, not locked, and an audible alarm in operation during test(s).
- 5.3 Barricades, Barriers, or Guarding of Test Area

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- 5.3.1 Barricades shall be set up around major equipment of the Microgrid Test Bed (i.e., saw-horse style barricades with plastic chain shall surround the test area containing the Gen-set Enclosure, Microgrid switching cabinets, plus load and fault bank cabinets).
- 5.3.2 Barricades set up at the entrance area to the Gen-set Enclosure and Microgrid Test Bed switching cabinets shall include “Danger – Test In Progress” signs.
- 5.4 Other Precautions
 - 5.4.1 During initial energizing tests all personnel shall remain within or adjacent to the Control Trailer while tests are being performed.
 - 5.4.2 All nonessential personnel shall either leave the main site or shall shelter in the Control Trailer.
- 5.5 Items to Verify Prior to Energizing Microgrid Test Bed Equipment.
 - 5.5.1 Test Engineer #1 or Technical Support Consultant shall verify that all personnel and visitors are properly protected and in assigned locations prior to performing each test.
 - 5.5.2 The test area is properly reviewed and secured.
 - 5.5.3 Auxiliary power sources fed from circuit breakers in electrical cabinets 9a and 9b are switched “On”, energizing down-line equipment, located in the Test Bed and Gen-set Enclosure.
 - 5.5.4 Gen-set Enclosure doors (i.e., located on East, South and West sides) must remain “Open” for proper airflow during Gen-set operation.
 - 5.5.5 Gen-set Enclosure exhaust fans and the coolant system/pump shall be “On” whenever one or more Gen-sets are operating.
- 5.6 Verify Operation of DAS and EMS, Prior to Performing Test Plan.
 - 5.6.1 All recording instrumentation shall be checked and readied for operation.
 - 5.6.2 Twelve PML Ion 7650 meters are distributed within the Microgrid Test Bed with locations shown in Figure 1. These meters are prime data collection elements in the system for DAS and EMS. They monitor electrical system conditions, plus acquire phase current and voltage waveforms; and

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calculate RMS values of voltage, current, active power, reactive power, and frequency.

- 5.6.3 An Ethernet network is provided, as shown in Figure 2, for communications between all meters, load control PLCs, and the DAS computer, using fiber-optic links and switches. The DAS and EMS computers are also networked into the local Dolan LAN. Additional serial links connect all SEL-351 relays, the static switch DSP control, and the Tecogen Gen-set controls to the EMS computer, using fiber optic converters.

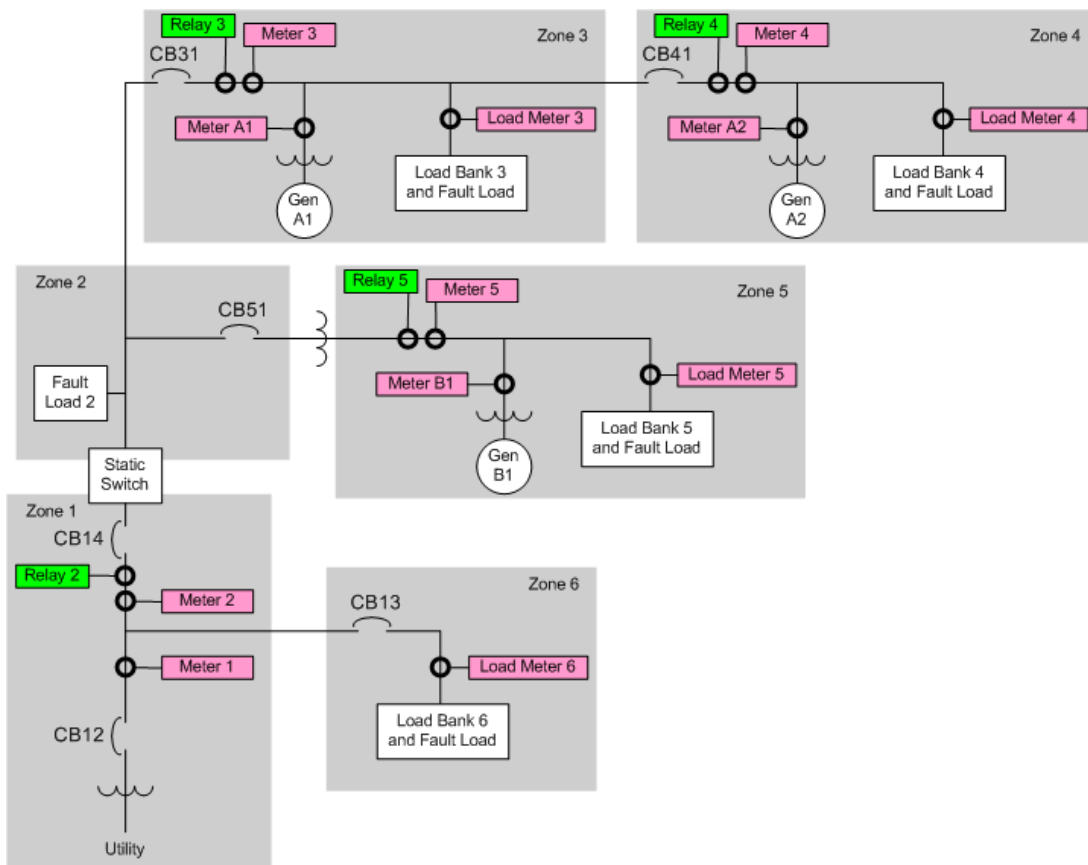


Figure 1 - Test Bed 1-Line with Meter and Relay Locations

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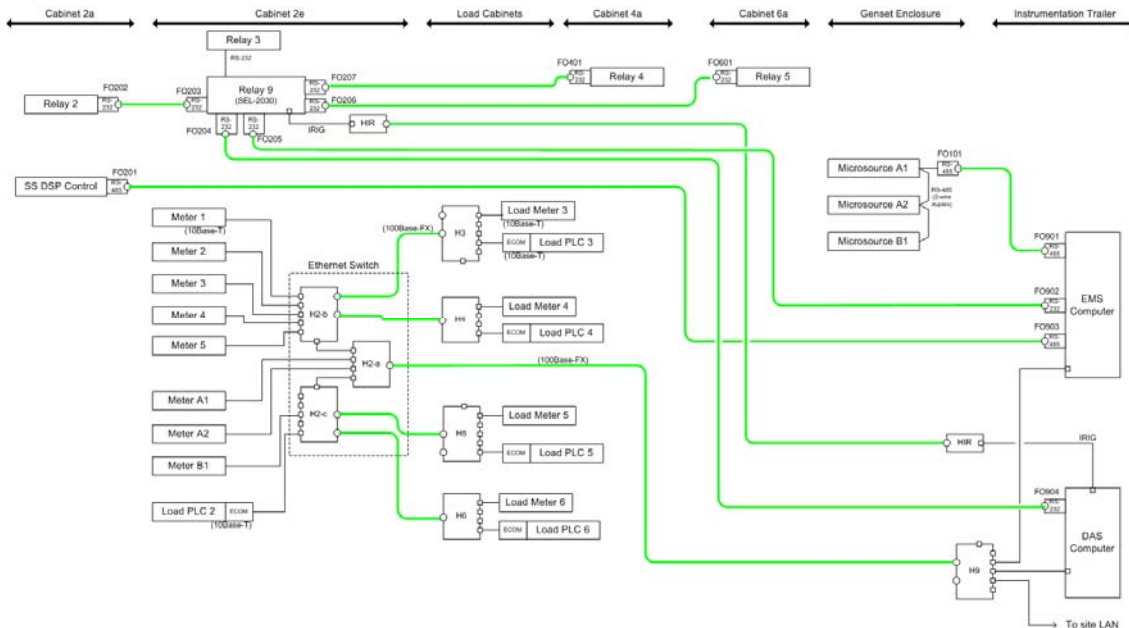


Figure 2 - DAS & EMS Data Network

6.0 Procedure – Microgrid Test Bed System Checkout

Objective: The tests described in Section 6 are designed to check control and operation of the static switch, basic power and voltage control of the Gen-sets, and a preliminary check of the protection scheme. The goal is to assure that the test bed is operating and ready to perform the tests described in the remaining sections of this test document. During these system checkout tests, the series inductor L11 shall be connected in the circuit to minimize any impact to the Test Bed.

6.1 Function of Static Switch

Objective: Check operation of the static switch, to assure it and its DSP control is operating as designed. This will include tests of dead-bus and synchronized closing, reverse power and IEEE 1547 protective relay functions. Waveform and RMS data from Meter 2 will be of prime interest. At this stage, the switch functions will be tested with a single Gen-set A1 online.

6.1.1 Start-up System, Synchronized Closing

Measure – Voltage waveforms for phases A, B & C on both sides of the static switch, current waveforms for phase A at the switch. To obtain the voltage across each phase of the switch, using Meter 2 and Meter A1 to measure the voltage on both sides of the switch.

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Performance Goal – Verification that when conditions are appropriate (within synchronization limits set in the EMS), the switch can perform a synchronized closing and thus give smooth closing transitions.

6.1.1.1 Verify the following items:

- 6.1.1.1.1 All alarms are reset on both the S&C PES and DSP, and that system is ready to start.
- 6.1.1.1.2 Circuit breakers in Cabinet 3 and Cabinet 8 to Load Banks are “Closed”.
- 6.1.1.1.3 CB 32 is “Closed”.
- 6.1.1.1.4 Set Gen-set A1 to the following set-points:
Gen-set A1 = Unit Power Control
Output Power Command = 20 kW
MG Power/Frequency Droop= -0.0833 Hz/kW
MG Voltage Command= 277 V
- 6.1.1.1.5 Set loads on Load Bank 3 and Load Bank 6 to 40kW.

6.1.1.2 Start the system with the “Start” command from the EMS. The system should enter the “Disconnect” State on the DSP, and the Gen-set side voltage at Meter A1 should indicate a frequency of approximately 59.65 Hz.

6.1.1.3 When conditions are appropriate, the static switch should do a synchronized “Close”. A smooth transition should occur from island to utility-connected mode in Gen-set A1. This will happen relatively quickly, after the “Start” command is issued.

6.1.1.4 When the static switch closes, “CONNECT” is displayed in the Control State block of the EMS, and “PES OK” is displayed in the PES Status block. Verify that the readings of power flow measurements are accurate.

6.1.1.5 Once steady state is reached, power flow should be ~ 60 kW at the remote location (Meter 1) and 20kW at the static switch (Meter 2); the frequency should stabilize to the grid frequency (~60Hz).

6.1.2 **Reverse Power, Grid Islanding (IEEE 1547, Loss of Utility Source).**

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Measure – RMS voltage and active power at static switch, current waveforms at the static switch and timing of event sequence.

Performance Goal – Verify the reverse power functionality of the static switch and confirm that the static switch islands the Microgrid for a reverse power condition due to an upstream utility operation at the PCC. Once the utility voltage returns to the IEEE 1547 limits, verify the proper operations of the reconnection timers (set by default to 300 seconds based on IEEE 1547 standard).

- 6.1.2.1 Set Gen-set A1 to the following set-points:
Gen-set A1 = Unit Power Control
Output Power Command = 20 kW
MG Power/Frequency Droop= -0.0833 Hz/kW
MG Voltage Command= 277 V
- 6.1.2.2 Set load on Load Bank 3 to 40kW and on Load Bank 6 to 20kW. Also, set load on the AEP Load Bank to 500kW.
- 6.1.2.3 Perform a synchronized “Close” of the static switch and verify closing after one minute.
- 6.1.2.4 Next disconnect the utility grid from the Microgrid via “Opening” CB1 (three-pole breaker). Note, the static switch should “Open” within 2 seconds of opening CB1. Once the static switch opens, no voltage is present on the grid side of the switch, which creates an “IEEE 1547 voltage test” event. Verify in the EMS screen that the indicator of this event is turned “ON”.
- 6.1.2.5 Verify in the “Event” Logger file that the above “Reverse Power” event was recorded, that the data acquisition was triggered and data was recorded, via a review of the DAS database.
- 6.1.2.6 Wait for approximately 20 seconds, and verify that the “IEEE 1547 voltage test” event remains high.
- 6.1.2.7 Reduce load on the AEP Load Bank to zero, than reconnect the grid by remote manual “Close” of CB1. The “IEEE 1547 voltage test” indicator should turn “Off”.
- 6.1.2.8 The static switch should not attempt to reconnect immediately, since IEEE 1547 reconnection timer is set to 300 seconds. When synchronization conditions are

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appropriate, the switch should attempt to do a synchronized “Close”.

6.1.2.9 Verify a synchronized “Close” of the static switch, after the IEEE 1547 reconnection timer has elapsed.

6.1.2.10 Verify in the DAS database that the synchronized “Close” of the static switch was triggered and data was recorded.

6.1.3 Reverse Power, Single -Phase (IEEE 1547 Voltage Event).

Measure – RMS voltage and active power at static switch, current waveforms for phase A at static switch, and timing of event sequence.

Performance Goal – Verification that the static switch islands the Microgrid when a reverse power condition, due an open-phase occurs. Note there are no single-phase breakers to disconnect the utility; reducing the load on one phase of the Microgrid will simulate the “open phase” condition. This condition does not properly test the reconnection logic, after an open phase, since the utility voltage will still be present on all three phases (i.e., test didn’t really disconnected a phase).

6.1.3.1 Set Gen-set A1 to the following set-points:

Gen-set A1 = Unit Power Control

Output Power Command = 20 kW

MG Power/Frequency Droop= -0.0833 Hz/kW

MG Voltage Command= 277 V

6.1.3.2 Select load on Load Bank 3 and Load Bank 6 to 40kW.

6.1.3.3 Start by removing the entire load on phase A of Load Bank 6. After this load change, the power measurement at the remote location (Meter 1) in phase A should be approximately 6.6 kW, and in phases B and C should each be approximately 20 kW.

6.1.3.4 Maintain zero load on phase A of Load Bank 6 and repeat the above load step change for Load Bank 3. Note, since the power measurement at remote location (Meter 1) in phase A is below the set threshold of 3.3kW, this should create a reverse power condition on phase A and open the

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static switch within 2 seconds. Once the switch opens, voltage should still be present on all phases of the utility grid side of the switch, the static switch will go to lockout by the DSP stopping the S&C PES switch (i.e., opening CB14 and going to the “Fault” state in the EMS).

6.1.3.5 Verify in the EMS that the system entered the “Fault” state, and check that the “Reverse power Anti-islanding, Microgrid Settings Reset” Alarm indicator has turned “On”.

6.1.3.6 Verify in “Event” Logger file that at the time when this test was performed, a “Reverse Power” event was recorded, DAS was triggered and data was recorded.

6.1.3.7 Remove the reverse power single phase condition by bringing all phase A loads at Zone 6 and at Zone 3 back to default conditions (i.e., 40kW each). The “Reverse power Anti-islanding, Microgrid Settings Reset Alarm” indicator should turn “Off”. Note, the static switch will need to be “Reset” to return it to service, as it will think this is a mis-dispatch of the generation within the Microgrid. Also, the static switch will not wait for the 300 seconds to reconnect to the utility grid.

6.1.3.8 Use the EMS to give a “Reset” command to clear all faults and events.

6.1.3.9 Once all events and alarms are cleared, “Start” the system and observe a synchronized closing of the static switch.

6.1.4 **Reverse Power, Anti-islanding Microgrid Settings Reset Measure** - RMS voltage and active power at static switch, current waveforms for phase A at switch and timing of event sequence.

Performance Goal - Verify that if a reverse power event occurs, due to a mismatch of Gen-set settings (Total Gen-set power > Microgrid load), the static switch will lockout and go to the “Fault” state, where user intervention is required.

6.1.4.1 Set Gen-set A1 to the following set-points:

Gen-set A1 = Unit Power Control
Output Power Command = 20 kW

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MG Power/Frequency Droop= -0.0833 Hz/kW

MG Voltage Command= 277 V

- 6.1.4.2 Select load on Load Bank 3 and Load Bank 6 to 40kW.
- 6.1.4.3 Once the static switch “Closes”, the power flow at Meter 1 is approximately 60kW.
- 6.1.4.4 Reduce the load to 0kW at Load Bank 6 and verify the power measurement at Meter 1 drops to roughly 20 kW. Wait 5 seconds and note that no reverse power trip should occur (i.e., above minimum 10 kW threshold value).
- 6.1.4.5 Reduce the load at Load Bank 3 by 5 kW, wait about 5 seconds and verify a reverse power trip occurs. If not, repeat the step 6.1.4.4, reducing load at Load Bank 3 by an additional 5kW. Continue until the reverse power condition occurs and the static switch “Opens”.
- 6.1.4.6 Once the static switch opens, since there is still voltage present in all phases of the grid side of the switch, the system will lockout by the DSP stopping the S&C PES switch (i.e., opening CB14 and going to the “Fault” state in the EMS).
- 6.1.4.7 Verify in the EMS that the system entered the “Fault” state, and check that the “Reverse Power Anti-islanding, Microgrid Settings Reset” alarm indicator has turned “On”.
- 6.1.4.8 Verify in the “Event” Logger file that at the time when this test was performed, a “Reverse Power” event was recorded, DAS was triggered and data was recorded.
- 6.1.4.9 Return load in Load Banks 3 and 6 back to 40kW.
- 6.1.4.10 Using the EMS, give a “Reset” command to clear all faults and events.
- 6.1.4.11 Once all events and alarms are cleared, “Start” the system and verify a synchronized closing of the static switch.

6.1.5 De-energized Bus (Dead Bus) Reclose

Measure – RMS voltage and active power at static switch, voltage on both sides of the switch, and timing of event sequence.

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Performance Goal - Verify that the static switch can close when de-energized bus conditions ($< 15V$) on the DG side are measured and that the Dead Bus Reclose algorithm requires user intervention (i.e., Operator needs to “Enable” the Dead Bus Reclose using pushbutton in the EMS).

6.1.5.1 Set Gen-set A1 to the following set-points:

Gen-set A1 = Unit Power Control

Output Power Command = 20 kW

MG Power/Frequency Droop= -0.0833 Hz/kW

MG Voltage Command= 277 V

6.1.5.2 Select load on Load Bank 3, and Load Bank 6 to 40kW.

6.1.5.3 Open the static switch using “Manual Open” command in the EMS.

6.1.5.4 Perform a controlled “Shutdown” of Gen-set A1.

6.1.5.5 Verify in the EMS display that “DG side Dead Bus” event indicator turns “On”. This confirms that the DSP detects a de-energized bus; the static switch doesn’t “CLOSE” because “Manual Open” is enabled and “Dead Bus Reclose” is disabled.

6.1.5.6 Remove “Manual Open” and verify that the switch still remains “Open”.

6.1.5.7 Enable “Dead Bus Reclose” by pressing the pushbutton in the EMS and verify the static switch “Close” event.

6.1.6 Power Quality Trip, Grid Islanding (IEEE 1547, Loss of Utility Source).

Measure – RMS voltage and active power at static switch, current waveforms at the static switch and timing of event sequence.


Performance Goal – Verify the reverse power functionality of the static switch and confirm that the static switch islands the Microgrid for a reverse power condition due to an upstream utility operation at the PCC. Once the utility voltage returns to the IEEE 1547 limits, verify the proper operations of the reconnection timers (set by default to 300 seconds based on IEEE 1547 standard).

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- 6.1.6.1 Set Gen-set A1 to the following set-points:
Gen-set A1 = Unit Power Control
Output Power Command = 20 kW
MG Power/Frequency Droop= -0.0833 Hz/kW
MG Voltage Command= 277 V
- 6.1.6.2 Set load on Load Bank 3 to 40kW and on Load Bank 6 to 20kW. Also, set load on the AEP Load Bank to 500kW.
- 6.1.6.3 Perform a synchronized “Close” of the static switch and verify closing after one minute.
- 6.1.6.4 Next disconnect the utility grid from the Microgrid via “Opening” CB1 (three-pole breaker). Note, the static switch should “Open” within the CBEMA requirement after the opening of CB1. Once the static switch opens, no voltage is present on the grid side of the switch, which creates an “IEEE 1547 voltage test” event. Verify in the EMS screen that the indicator of this event is turned “ON”.
- 6.1.6.5 Verify in the “Event” Logger file that the above “Reverse Power” event was recorded, that the data acquisition was triggered and data was recorded, via a review of the DAS database.
- 6.1.6.6 Wait for approximately 20 seconds, and verify that the “IEEE 1547 voltage test” event remains high.
- 6.1.6.7 Reduce load on the AEP Load Bank to zero, than reconnect the grid by remote manual “Close” of CB1. The “IEEE 1547 voltage test” indicator should turn “Off”.
- 6.1.6.8 The static switch should not attempt to reconnect immediately, since IEEE 1547 reconnection timer is set to 300 seconds. When synchronization conditions are appropriate, the switch should attempt to do a synchronized “Close”.
- 6.1.6.9 Verify a synchronized “Close” of the static switch, after the IEEE 1547 reconnection timer has elapsed.
- 6.1.6.10 Verify in the DAS database that the synchronized “Close” of the static switch was triggered and data was recorded.

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7.0 Procedure – Validate Protection Settings & Initial Fault Testing

Objective: The tests described in Section 7 are designed to examine a preliminary set of fault (i.e., overload simulating a fault) condition tests to ensure protection and safety of the Microgrid Test Bed, while performing other planned tests. The goal is to test and adjust protection settings to achieve the most ideal conditions and protection design. Tests performed in this section will include inductor L11 in the circuit, reflecting weak grid conditions.

Definitions – To maintain a common understanding of Gen-set control modes during tests proposed in the following paragraphs:

- Unit Power Control Mode involves the amount of power (i.e., kW) being injected into the Zone from the Gen-set being controlled.
- Zone Power Control Mode involves the amount of power (i.e., kW) entering/exiting the Zone which controls the output of the Gen-set in that Zone.

Measure – During each fault event record waveforms of phase currents and line-to-neutral voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5). Record the relay element that caused the “TRIP” with trip times for each relay relative to when the fault condition was applied.

Performance Goal - The fault (i.e., overload simulating a fault) condition tests are intended to cover the basic concept of the protection design and to study its effectiveness (e.g., zero-sequence, negative-sequence and residual currents for line-to-ground faults; negative-sequence or (I^2t) protection for phase-to-phase faults). For the majority of these test scenarios, the static switch should “OPEN” first, followed by a “TRIP” at the specified relay. Confirm the protective action detailed in the Protection document.

7.1 Validate Zone 4 Circuit Breaker Settings, Utility Connected

Performance Goal - Initially test a three-phase balanced fault condition in Zone 4 to verify I^2t protection. Then test a single line-to-ground fault condition in Zone 4 to verify zero-sequence, negative-sequence or residual over-current protection.

- 7.1.1 Perform the Microgrid Test Bed Lockout/Tagout Procedure, described in Section 4.7.
- 7.1.2 To simulate a high impedance three-phase ungrounded fault, setup the Overload Load Bank for 85kW and connect portable cable/plug into the exterior receptacle of Cabinet 5a.

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- 7.1.3 Install/physically connect portable overload cabling inside the cabinet at the outlet receptacle to phases A, B, and C (i.e., connecting and tightening the bolted connection).
- 7.1.4 Reverse the Microgrid Test Bed Lockout/Tagout Procedure.
- 7.1.5 Verify CB43 is Closed along with the circuit breakers to the Overload and Load Banks, manually “ARM” the key switch in the cabinet and close/lock the entry doors to Cabinet 5.
- 7.1.6 Verify that the Microgrid Test Bed is energized with nominal voltages indicated on all three phases at Meter 1.
- 7.1.7 Using the Load Control program, set the load in Load Bank 4 to 60kW.
- 7.1.8 Using the EMS, give a “Reset” command to clear all faults and events in the system.
- 7.1.9 After the dead-bus closing of the static switch from the EMS, the Microgrid Test Bed is connected to the utility grid with 60kW at Meter 2 and Meter 1.
- 7.1.10 Using the DAS Load Control program set the duration of the simulated fault to 100 seconds, set the software to “ARM” and initiate a three-phase, ungrounded fault (overload) in Zone 4, which adds 85kW to the 60kW load.
- 7.1.11 Verify that CB41 “TRIPS” first on over-current clearing the fault. Breaker K42 should Open under PLC control, removing the fault of the Overload Load Bank.
- 7.1.12 Verify in the DAS Database that:
 - 7.1.12.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “Trip” with trip times for each relay relative to when the fault was applied.
 - 7.1.12.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.
- 7.1.13 Remove load from Load Bank 4 to complete this simulated fault test event. Turn the key switch in Cabinet 5 to the “Off” position.

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- 7.1.14 Perform the Microgrid Test Bed lockout/Tagout Procedure in Section 4.7 to prepare for a single-phase-to-ground fault (i.e., overload) test in Zone 4.
- 7.1.15 Within Cabinet 5a, physically remove the overload cabling inside the cabinet from phases B and C.
- 7.1.16 Change the wiring in Cabinet 5 between the external connector and the fault contactor K42 for a single phase fault of 28kW between Phase A and ground (i.e., connecting and tightening the bolted connections).
- 7.1.17 Reverse the Microgrid Test Bed Lockout/Tagout Procedure.
- 7.1.18 Verify CB43 is “Closed” along with the circuit breakers to the Load Bank, manually “ARM” the key switch in the cabinet and close entry doors to Cabinet 5.
- 7.1.19 Using the Load Control program, set the load in Load Bank 4 to 60 kW.
- 7.1.20 Using the EMS, give a “Reset” command to clear all faults and events in the system.
- 7.1.21 After performing a dead-bus closing of the static switch, the Microgrid Test Bed is connected to the utility grid with 60kW at Meter 2 and Meter 1.
- 7.1.22 Using the DAS Load Control program, set the duration of the simulated fault to 10 seconds, set the software to “ARM” and initiate a single-phase to ground fault (overload) in Zone 4, which adds 28kW to the 20kW load on A-phase.
- 7.1.23 Verify that the static switch “TRIPS” first on Ground over-current, which clears the fault (overload), followed by breaker CB41. Breaker K42 should Open under PLC control, removing the fault of the Overload Load Bank.
- 7.1.24 Verify in the DAS Database that:
 - 7.1.24.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.

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7.1.24.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.

7.1.25 Remove load from Load Bank 4 and “STOP” the static switch.

7.1.26 Perform the Microgrid Test Bed Lockout/Tagout Procedure, described in Section 4.7.

7.1.27 Remove the Overload Load Bank portable cable/plug from the exterior receptacle of Cabinet 5a.

7.1.28 Physically remove the portable overload cabling inside Cabinet 5 between A-phase to ground.

7.1.29 Reverse the Microgrid Test Bed Lockout/Tagout Procedure.

7.1.30 Verify CB41 and the breaker to the Load Bank is closed. Close the entry doors to Cabinet 5 to complete this fault test event.

7.2 **Validate Zone 3 Circuit Breaker Settings, Utility Connected**
Performance Goal - Initially test a three-phase balanced fault condition in Zone 3 to verify I^2t protection. Then test a single line-to-ground fault condition in Zone 3 to verify zero-sequence, negative-sequence or residual over-current protection.

7.2.1 Repeat steps 7.1.1 through 7.1.30 to simulate a three-phase ungrounded fault (i.e., overload), and then a single-phase to ground fault (i.e., overload) on B-phase in Zone 3, Cabinet 3 and circuit breaker CB31. Note, for this test 60kW of additional load is required in Zone 4 on Load Bank 4.

7.3 **Validate Zone 5 Circuit Breaker Settings, Utility Connected**
Performance Goal - Initially test a three-phase balanced fault condition in Zone 5 to verify I^2t protection. Then test a single line-to-ground fault condition in Zone 5 to verify zero-sequence, negative-sequence or residual over-current protection.

7.3.1 Repeat steps 7.1.1 through 7.1.30 to simulate a three-phase ungrounded fault (i.e., overload), and then a single-phase to ground fault (i.e., overload) on C-phase in Zone 5, Cabinet 7b and circuit breaker CB51.

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- 7.4 **Zone 4 Three-Phase Un-grounded Fault, Gen-sets (A1+A2) & Utility Connected**
Performance Goal - Test a three-phase balanced fault condition in Zone 4 with Gen-sets A1 and A2 operating in-parallel with the utility grid to verify I^2t protection, plus confirm a reverse power event after the Zone breaker “opens”.
- 7.4.1 Perform the Microgrid Test Bed Lockout/Tagout Procedure, described in Section 4.7.
 - 7.4.2 Setup the Overload Load Bank for a three-phase un-grounded fault of 85kW and connect portable cable/plug into the exterior receptacle of Cabinet 5a.
 - 7.4.3 Install/physically connect portable overload cabling inside the cabinet from the outlet receptacle to phases A, B, and C (i.e., connecting and tightening the bolted connections).
 - 7.4.4 Reverse the Microgrid Test Bed Lockout/Tagout Procedure.
 - 7.4.5 Verify CB43 is “Closed” along with the circuit breakers to the Load Banks, and manually “ARM” the key switch in the cabinet and close the entry doors to Cabinet 5.
 - 7.4.6 Verify that the static switch is “Open”.
 - 7.4.7 Set Gen-sets A1 and A2 to the following set-points:
 Gen-set A1 and A2 = Unit Power Control Mode
 Output Power Command of A1 = 50kW
 Output Power Command of A2 = 20kW
 MG Power/Frequency Droop= -0.0833 Hz/kW
 MG Voltage Command= 277 V.
 - 7.4.8 Select load on Load Bank 3 to 10kW and Load Bank 6 to 40kW, and load on Load Bank 4 to 50kW.
 - 7.4.9 Using EMS, give a “Reset” command to clear all faults and events.
 - 7.4.10 Once all events and alarms are cleared, “Start” the Gen-sets. Note, there is 60kW of load in the microgrid when the first Gen-set starts, causing it to go to full (i.e., 60kW) power as soon as it connects and simulating a Black Start into 60kW.
 - 7.4.11 Once the Gen-sets are running and on-line, which will take a few minutes to occur, use the EMS to put the static switch in “Start” mode and verify a synchronized closing of the static switch. Note, if the static switch does not “Close”, reduce output of Gen-set A1

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to 30kW (this will reduce frequency as A1 and A2 change their frequency to balance generation loss of 10kW).

- 7.4.12 After synchronized closing of the static switch, the Microgrid Test Bed is connected to the utility grid with -10kW at Meter 2 and 30kW at Meter 1.
- 7.4.13 Using the DAS Load Control program, set the duration of the fault (overload) to 100 seconds, set the software to “ARM” and initiate a three-phase, ungrounded fault (overload) in Zone 4, which adds 85kW to the 50kW load.
- 7.4.14 Verify that CB41 “TRIPS” first on over-current, which clears the fault and shuts down Gen-set A2. Breaker K42 should Open under PLC control, removing the fault of the Overload Load Bank.
- 7.4.15 Verify that the static switch “Opens”, due to reverse power and Gen-set A1 continues to operate, but reduces its output power to 10kW.
- 7.4.16 Verify in the DAS Database that:
 - 7.4.16.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.
 - 7.4.16.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.
- 7.4.17 Shutdown Gen-set A1, remove remaining load, “STOP” the static switch, and re-close CB41 to complete this fault (overload) test event.

7.5 **Zone 3 A-Phase Line-to-Ground Fault, Gen-set A1 & Utility Connected**

Performance Goal - Test a single line-to-ground fault condition in Zone 3 with Gen-sets A1 operating in-parallel with the utility grid to verify zero-sequence, negative-sequence or residual over-current protection.

- 7.5.1 Perform the Microgrid Test Bed Lockout/Tagout Procedure, described in Section 4.7.

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- 7.5.2 Remove the Overload Load Bank portable cable/plug from the exterior receptacle and physically remove the portable overload cabling inside Cabinet 5a.
- 7.5.3 Setup the Overload Load Bank for a single-phase fault (overload) on A-phase of 28kW and connect the portable cable/plug into the exterior receptacle of Cabinet 3a
- 7.5.4 Install/physically connect the portable overload cabling inside Cabinet 3 from the outlet receptacle to A-phase and Ground (i.e., connecting and tightening the bolted connections).
- 7.5.5 Reverse the Microgrid Test Bed Lockout/Tagout Procedure.
- 7.5.6 Verify CB33 is “Closed” along with the circuit breakers to the Load Banks, manually “ARM” key switch in the cabinet and close the entry door to Cabinet 3.
- 7.5.7 Set Gen-set A1 to the following set-points:
Gen-set A1 = Unit Power Control Mode
Output Power Command = 20 kW
MG Power/Frequency Droop= -0.0833 Hz/kW
MG Voltage Command= 277 V.
- 7.5.8 Select loads on Load Bank 3 and Load Bank 6 to 40kW.
- 7.5.9 Using EMS, give a “Reset” command to clear all faults and events
- 7.5.10 Once all events and alarms are cleared, “Start” Gen-set A1.
- 7.5.11 Once the Gen-set is running and on-line, use EMS to put the static switch in “Start” mode. Verify synchronized closing of the static switch.
- 7.5.12 After synchronized closing of the static switch, the Microgrid Test Bed is connected to the utility grid with 20kW at Meter 2 and 60kW at Meter 1.
- 7.5.13 Using the DAS Load Control program, set the duration of the fault (overload) to 10 seconds, set the software to “ARM” and initiate a Phase A-to ground fault in Zone 3.
- 7.5.14 Verify that the static switch “TRIPS” first followed by breaker CB31, which clears the fault and shuts down Gen-set A1. Breaker K32 should then Open under PLC control, removing the fault of the Overload Load Bank.

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7.5.15 Verify power flow change of 0kW at Meter 2 and 40kW at Meter 1, serving the 40kW in Load Bank 6.

7.5.16 Verify in the DAS Database that:

7.5.16.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.

7.5.16.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.

7.5.17 Remove remaining load from the Microgrid Test Bed, “STOP” the static switch, and re-close breaker CB31 to complete this fault test event.

7.6 **Zone 3 A-Phase Line-to-Ground Fault, Gen-sets (A1+A2) & Utility Connected**

Performance Goal - Test a single line-to-ground fault condition in Zone 3 with Gen-sets A1 and A2 operating in-parallel with the utility grid to verify zero-sequence, negative-sequence or residual over-current protection.

7.6.1 Verify CB33 is “Closed” along with the circuit breakers to the Load Banks, manually “ARM” key switch in the cabinet and close the entry doors to Cabinet 3.

7.6.2 Set Gen-sets A1 & A2 to the following set-points:

Gen-set A1 & A2 = Unit Power Control Mode
Output Power Command = 20 kW each
MG Power/Frequency Droop= -0.0833 Hz/kW
MG Voltage Command= 277 V.

7.6.3 Using EMS, give a “Reset” command to clear all faults and events.

7.6.4 Once all events and alarms are cleared, “Start” the Gen-sets.

7.6.5 Once the Gen-sets are running and on-line, select loads on Load Bank 3, Load Bank 4 and Load Bank 6 to 40kW.

7.6.6 Use EMS to put the static switch in “Start” mode. Verify synchronized closing of the static switch.

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- 7.6.7 After the synchronized closing of the static switch, the Microgrid Test Bed is connected to the utility grid with 40kW at Meter 2 and 80kW at Meter 1.
- 7.6.8 Using the DAS Load Control program, set the duration of the fault (overload) to 10 seconds, set the software to “ARM” and initiate a A-phase to ground fault in Zone 3.
- 7.6.9 Verify that the static switch “Trips/Opens” first followed by breaker CB41 opening on zero-sequence current and Gen-set A2 will shut down. About 7 cycles after this protection sequence, CB31 will Trip/Open and Gen-set A1 will shut down. Breaker K32 should “Open” under PLC control, removing the fault on the Overload Load Bank.
- 7.6.10 Verify power flow change of 0kW at Meter 2 and 40kW at Meter 1, serving the 40kW in Load Bank 6.
- 7.6.11 Verify in the DAS Database that:
 - 7.6.11.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.
 - 7.6.11.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.
- 7.6.12 Remove remaining load from the Microgrid Test Bed, “STOP” the static switch, and re-close breakers CB41 and CB31 to complete this fault test.

7.7 Zone 5 B-Phase Line-to-Ground Fault, Gen-set B1 & Utility Connected

Performance Goal - Test a single line-to-ground fault condition in Zone 5 with Gen-sets B1 operating in-parallel with the utility grid to verify zero-sequence, negative-sequence or residual over-current protection.

- 7.7.1 Perform the Microgrid Test Bed Lockout/Tagout Procedure, described in Section 4.7.
- 7.7.2 Remove the Overload Load Bank portable cable/plug from the exterior receptacle and physically remove the portable overload cabling inside Cabinet 3a.

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- 7.7.3 Setup the Overload Load Bank for a single-phase fault (overload) on B-phase of 28kW and connect the portable cable/plug into the exterior receptacle of Cabinet 7a.
- 7.7.4 Install/physically connect the portable overload cabling inside Cabinet 7 from the outlet receptacle to B-phase and Ground (i.e., connecting and tightening the bolted connections).
- 7.7.5 Reverse the Microgrid Test Bed Lockout/Tagout Procedure.
- 7.7.6 Verify breaker CB53 is “Closed” along with the circuit breakers to the Load Banks, manually “ARM” the key switch in the cabinet, and close the entry doors to Cabinet 7.
- 7.7.7 Set Gen-sets B1 to the following set-points:
Gen-set B1 = Unit Power Control Mode
Output Power Command = 20 kW
MG Power/Frequency Droop= -0.0833 Hz/kW
MG Voltage Command= 277 V.
- 7.7.8 Select loads on Load Bank 3 and Load Bank 6 to 40kW.
- 7.7.9 Using EMS, give a “Reset” command to clear all faults and events
- 7.7.10 Once all events and alarms are cleared, “Start” Gen-set B1.
- 7.7.11 Once the Gen-set is running and on-line, use EMS to put the static switch in “Start” mode. Verify synchronized closing of the static switch.
- 7.7.12 After synchronized closing of the static switch, the Microgrid Test Bed is connected to the utility grid with 20kW at Meter 2 and 60kW at Meter 1.
- 7.7.13 Using the DAS Load Control program, set the duration of the fault (overload) to 10 seconds, set the software to “ARM” and initiate a B-phase to ground fault in Zone 5.
- 7.7.14 Verify that CB51 “Opens” first on differential or zero-sequence current which clears the fault and shuts down Gen-set B1. Breaker K52 should then Open under PLC control, removing the fault on the Overload Load Bank. Note, the static switch is not expected to “Trip” during this test event.
- 7.7.15 Verify power flow change of 40kW at Meter 2 and 80kW at Meter 1, serving the 40kW in Load Bank 3 and Load Bank 6.
- 7.7.16 Verify in the DAS Database that:

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7.7.16.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.

7.7.16.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.

7.7.17 Remove remaining load from the Microgrid Test Bed, “STOP” the static switch, and re-close breaker CB51 to complete this fault test event.

7.8 **Zone 5 B-Phase Line-to-Ground Fault, Gen-sets (A1+B1) & Utility Connected**

Performance Goal - Test a single line-to-ground fault condition in Zone 5 with Gen-sets A1 and B1 operating in-parallel with the utility grid to verify zero-sequence, negative-sequence or residual over-current protection. This test is similar to the prior test, but evaluates the resultant impact of two Gen-sets operating during a fault condition.

7.8.1 Verify CB31 and CB51 are “Closed” along with the circuit breakers to the Load Banks, manually “ARM” key switch in the cabinet and close the entry doors to Cabinet 7.

7.8.2 Set Gen-sets A1 & B1 to the following set-points:
Gen-set A1 & B1 = Unit Power Control Mode
Output Power Command = 20 kW each
MG Power/Frequency Droop= -0.0833 Hz/kW
MG Voltage Command= 277 V.

7.8.3 Using EMS, give a “Reset” command to clear all faults and events.

7.8.4 Once all events and alarms are cleared, “Start” the Gen-sets.

7.8.5 Once the Gen-sets are running and on-line, select loads on Load Bank 3, Load Bank 4 and Load Bank 6 to 40kW.

7.8.6 Use EMS to put the static switch in “Start” mode. Verify synchronized closing of the static switch.

7.8.7 After the synchronized closing of the static switch, the Microgrid Test Bed is connected to the utility grid with 40kW at Meter 2 and 80kW at Meter 1.

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- 7.8.8 Using the DAS Load Control program, set the duration of the fault (overload) to 10 seconds, set the software to “ARM” and initiate a B-phase to ground fault in Zone 3.
- 7.8.9 Verify that CB51 “Opens” first on zero-sequence current which clears the fault and shuts down Gen-set B1. Breaker K52 should then Open under PLC control, removing the fault of the Overload Load Bank. Note, the static switch is not expected to “Trip” during this test event.
- 7.8.10 Verify the static switch remains “Closed”, Gen-set A1 continues to operate, and the power flow change of 60kW at Meter 2 and 100kW at Meter 1.
- 7.8.11 Verify in the DAS Database that:
 - 7.8.11.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.
 - 7.8.11.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.
- 7.8.12 Remove remaining load from the Microgrid Test Bed, shut down Gen-set A1, “STOP” the static switch, and re-close breaker CB51 to complete this fault test.

7.9 Zone 4 B-Phase Line-to-Ground Fault, Gen-sets (A1+A2) & Utility Connected

Performance Goal - Test a single line-to-ground fault condition in Zone 4 with Gen-sets A1 and A2 operating in-parallel with the utility grid to verify zero-sequence, negative-sequence or residual over-current protection.

- 7.9.1 Perform the Microgrid Test Bed Lockout/Tagout Procedure, described in Section 4.7.
- 7.9.2 Remove the Overload Load Bank portable cable/plug from the exterior receptacle and physically remove the portable overload cabling inside Cabinet 7a.

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- 7.9.3 Setup the Overload Load Bank for a single-phase fault (overload) on B-phase of 28kW and connect the portable cable/plug into the exterior receptacle of Cabinet 5a
- 7.9.4 Install/physically connect the portable overload cabling inside Cabinet 5 from the outlet receptacle to B-phase and Ground (i.e., connecting and tightening the bolted connections).
- 7.9.5 Reverse the Microgrid Test Bed Lockout/Tagout Procedure.
- 7.9.6 Verify CB43 is “Closed” along with the circuit breakers to the Load Banks, manually “ARM” key switch in the cabinet and close the entry doors to Cabinet 5.
- 7.9.7 Set Gen-sets A1 & A2 to the following set-points:
Gen-set A1 & A2 = Unit Power Control Mode
Output Power Command = 20 kW each
MG Power/Frequency Droop= -0.0833 Hz/kW
MG Voltage Command= 277 V.
- 7.9.8 Using EMS, give a “Reset” command to clear all faults and events
- 7.9.9 Once all events and alarms are cleared, “Start” the Gen-sets.
- 7.9.10 Once the Gen-sets are running and on-line, select loads on Load Bank 3, Load Bank 4 and Load Bank 6 to 40kW.
- 7.9.11 Use EMS to put the static switch in “Start” mode. Verify synchronized closing of the static switch.
- 7.9.12 After the synchronized closing of the static switch, the Microgrid Test Bed is connected to the utility grid with 40kW at Meter 2 and 80kW at Meter 1.
- 7.9.13 Using the DAS Load Control program, set the duration of the fault (overload) to 10 seconds, set the software to “ARM” and initiate a B-phase to ground fault in Zone 4.
- 7.9.14 Verify that the static switch “Trips/Opens” first followed by breaker CB41 opening zero-sequence current, which clears the fault and shuts down Gen-set A2. Breaker K42 should “Open” under PLC control, removing the fault of the Overload Load Bank. Gen-set A1 should increase to 40kW to serve the load in Zone 3.
- 7.9.15 Verify power flow change of 0kW at Meter 2 and 40kW at Meter 1, serving the 40kW in Load Bank 6.
- 7.9.16 Verify in the DAS Database that:

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- 7.9.16.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.
- 7.9.16.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.
- 7.9.17 Remove remaining load from the Microgrid Test Bed, shut down Gen-set A1, “STOP” the static switch, and re-close breaker CB41 to complete this fault test.
- 7.10 **Zone 2 C-Phase Line-to-Ground Fault, Gen-sets (A1+B1) & Utility Connected**
 - Performance Goal** - Test a single line-to-ground fault condition in Zone 2 with Gen-sets A1 and B1 operating in-parallel with the utility grid to verify zero-sequence, negative-sequence or residual over-current protection.
 - 7.10.1 Perform the Microgrid Test Bed Lockout/Tagout Procedure, described in Section 4.7.
 - 7.10.2 Remove the Overload Load Bank portable cable/plug from the exterior receptacle and physically remove the portable overload cabling inside Cabinet 5a.
 - 7.10.3 Setup the Overload Load Bank for a single-phase fault (overload) on C-phase of 28kW and connect the portable cable/plug into the exterior receptacle of Cabinet 2d
 - 7.10.4 Install/physically connect the portable overload cabling inside Cabinet 2 from the outlet receptacle to C-phase and Ground (i.e., connecting and tightening the bolted connections).
 - 7.10.5 Reverse the Microgrid Test Bed Lockout/Tagout Procedure.
 - 7.10.6 Verify CB31 and CB51 are “Closed” along with the circuit breakers to the Load Banks, manually “ARM” key switch in the cabinet and close the entry doors to Cabinet 2d.
 - 7.10.7 Set Gen-sets A1 & B1 to the following set-points:
 - Gen-set A1 & B1 = Unit Power Control Mode
 - Output Power Command = 20 kW each

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MG Power/Frequency Droop= -0.0833 Hz/kW

MG Voltage Command= 277 V.

- 7.10.8 Using EMS, give a “Reset” command to clear all faults and events
- 7.10.9 Once all events and alarms are cleared, “Start” the Gen-sets.
- 7.10.10 Once the Gen-sets are running and on-line, select loads on Load Bank 3, Load Bank 4 and Load Bank 6 to 40kW
- 7.10.11 Use EMS to put the static switch in “Start” mode. Verify synchronized closing of the static switch.
- 7.10.12 After the synchronized closing of the static switch, the Microgrid Test Bed is connected to the utility grid with 40kW at Meter 2 and 80kW at Meter 1.
- 7.10.13 Using the DAS Load Control program, set the duration of the fault (overload) to 10 seconds, set the software to “ARM” and initiate a C-phase to ground fault in Zone 2.
- 7.10.14 Verify that the static switch “Trips/Opens” first followed by breaker CB51 opening on line-to-neutral under-voltage and shuts down Gen-set B1. About 7 cycles after this protection sequence, CB31 will Trip/Open on differential current and Gen-set A1 will shut down. Breaker K22 should “Open” under PLC control, removing the fault of the Overload Load Bank.
- 7.10.15 Verify power flow change of 0kW at Meter 2 and 40kW at Meter 1, serving the 40kW in Load Bank 6.
- 7.10.16 Verify in the DAS Database that:
 - 7.10.16.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.
 - 7.10.16.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.
- 7.10.17 Remove remaining load from the Microgrid Test Bed, “STOP” the static switch, and re-close breakers CB51 and CB31 to complete this fault test.

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7.11 Zone 6 C-Phase Line-to-Ground Fault, Gen-set A1 & Utility Connected

Performance Goal - Test a single line-to-ground fault condition in Zone 6 with Gen-set A1 operating in-parallel with the utility grid to verify I^2t protection.

- 7.11.1 Perform the Microgrid Test Bed Lockout/Tagout Procedure, described in Section 4.7.
- 7.11.2 Remove the Overload Load Bank portable cable/plug from the exterior receptacle and physically remove the portable overload cabling inside Cabinet 2d.
- 7.11.3 Setup the Overload Load Bank for a single-phase fault (overload) on C-phase of 28kW and connect the portable cable/plug into the exterior receptacle of Cabinet 8a
- 7.11.4 Install/physically connect the portable overload cabling inside Cabinet 8 from the outlet receptacle to C-phase and Ground (i.e., connecting and tightening the bolted connections).
- 7.11.5 Reverse the Microgrid Test Bed Lockout/Tagout Procedure.
- 7.11.6 Verify CB63 is “Closed” along with the circuit breakers to the Load Banks, manually “ARM” the key switch in the cabinet and close the entry doors to Cabinet 8.
- 7.11.7 Set Gen-set A1 to the following set-points:
Gen-set A1 = Unit Power Control Mode
Output Power Command = 20 kW
MG Power/Frequency Droop= -0.0833 Hz/kW
MG Voltage Command= 277 V.
- 7.11.8 Select loads on Load Bank 3 and Load Bank 6 to 40kW.
- 7.11.9 Using EMS, give a “Reset” command to clear all faults and events.
- 7.11.10 Once all events and alarms are cleared, “Start” the Gen-sets.
- 7.11.11 Once the Gen-sets are running and on-line, use EMS to put the static switch in “Start” mode. Verify synchronized closing of the static switch.
- 7.11.12 After the synchronized closing of the static switch, the Microgrid Test Bed is connected to the utility grid with 20kW at Meter 2 and 60kW at Meter 1.

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- 7.11.13 Using the DAS Load Control program, set the duration of the fault (overload) to 100 seconds, set the software to “ARM” and initiate a Phase C-to-ground fault in Zone 6.
- 7.11.14 Verify that the static switch “TRIPS” first, followed by breaker CB13 opening, which clears the fault. Breaker K62 should “Open” under PLC control, removing the fault of the Overload Load Bank.
- 7.11.15 Verify that Gen-set A1 power output increases from 20kW to 40kW to serve the 40kW load in Load Bank 3.
- 7.11.16 Verify in the DAS Database that:
 - 7.11.16.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.
 - 7.11.16.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.
- 7.11.17 Shutdown Gen-set A1, “STOP” the static switch, and remove load from the Microgrid Test Bed to complete this fault test event.

7.12 Zone 6 C-Phase Line-to-Ground Fault, Gen-set (A1+B1) & Utility Connected

Performance Goal - Test a single line-to-ground fault condition in Zone 6 with Gen-sets A1 and B1 operating in-parallel with the utility grid to verify I^2t protection. This test is similar to the prior test, but evaluates the resultant impact of two Gen-sets operating during a fault condition.

- 7.12.1 Verify CB63 is “Closed” along with the circuit breakers to the Load Banks. Manually “ARM” the key switch in the cabinet and close the entry doors to Cabinet 8.
- 7.12.2 Set Gen-set A1 & B1 to the following set-points:
 Gen-set A1 & B1 = Unit Power Control Mode
 Output Power Command = 20 kW each
 MG Power/Frequency Droop= -0.0833 Hz/kW
 MG Voltage Command= 277 V.

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- 7.12.3 Select loads on Load Bank 3, Load Bank 5 and Load Bank 6 to 40kW.
- 7.12.4 Using EMS, give a “Reset” command to clear all faults and events.
- 7.12.5 Once all events and alarms are cleared, “Start” the Gen-sets.
- 7.12.6 Once the Gen-sets are running and on-line, use EMS to put the static switch in “Start” mode. Verify synchronized closing of the static switch.
- 7.12.7 After the synchronized closing of the static switch, the Microgrid Test Bed is connected to the utility grid with 40kW at Meter 2 and 80kW at Meter 1.
- 7.12.8 Using the DAS Load Control program, set the duration of the fault (overload) to 100 seconds, set the software to “ARM” and initiate a Phase C-to-ground fault in Zone 6.
- 7.12.9 Verify that the static switch “TRIPS” first, followed by breaker CB13 opening, which clears the fault. Breaker K62 should “Open” under PLC control, removing the fault of the Overload Load Bank.
- 7.12.10 Verify that Gen-set A1 and B1 power output increases from 20kW to 40kW to serve the 40kW load in Load Bank 3 and Load Bank 5.
- 7.12.11 Verify in the DAS Database that:
 - 7.12.11.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.
 - 7.12.11.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.
- 7.12.12 Shutdown Gen-set A1 & A2, “STOP” the static switch, and remove load from the Microgrid Test Bed to complete this fault test event.
- 7.12.13 Verify CB63 is “Closed” along with the circuit breakers to the Load Bank; and close the entry doors to Cabinet 8.

7.13 **Zone 3 A-to-B Phase Fault, Gen-set (A1+A2) & Utility Connected** **Performance Goal** - Test a phase-to-phase fault condition in Zone 3 with

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Gen-sets A1 and A2 operating in-parallel with the utility grid to verify negative-sequence, I^2t protection or residual over-current protection.

- 7.13.1 Perform the Microgrid Test Bed Lockout/Tagout Procedure, described in Section 4.7.
- 7.13.2 Remove the Overload Load Bank portable cable/plug from the exterior receptacle and physically remove the portable overload cabling inside Cabinet 8a.
- 7.13.3 Setup the Overload Load Bank for a phase-to-phase fault (overload) between A and B phases of 84kW and connect the portable cable/plug into the exterior receptacle of Cabinet 3a
- 7.13.4 Install/physically connect the portable overload cabling inside Cabinet 3 from the outlet receptacle to A and B phases (i.e., connecting and tightening the bolted connections).
- 7.13.5 Reverse the Microgrid Test Bed Lockout/Tagout Procedure.
- 7.13.6 Verify CB33 is “Closed” along with the circuit breakers to the Load Banks, manually “ARM” the key switch in the cabinet and close the entry doors to Cabinet 3.
- 7.13.7 Set Gen-set A1 & A2 to the following set-points:
Gen-set A1 & A2 = Unit Power Control Mode
Output Power Command = 20 kW each
MG Power/Frequency Droop= -0.0833 Hz/kW
MG Voltage Command= 277 V.
- 7.13.8 Using EMS, give a “Reset” command to clear all faults and events.
- 7.13.9 Once all events and alarms are cleared, “Start” the Gen-sets.
- 7.13.10 Once the Gen-sets are running and on-line, select loads on Load Bank 3, Load Bank 4 and Load Bank 6 to 40kW.
- 7.13.11 Use EMS to put the static switch in “Start” mode. Verify synchronized closing of the static switch.
- 7.13.12 After the synchronized closing of the static switch, the Microgrid Test Bed is connected to the utility grid with 40kW at Meter 2 and 80kW at Meter 1.
- 7.13.13 Using the DAS Load Control program, set the duration of the fault (overload) to 10 seconds, set the software to “ARM” and initiate a Phase A-to-Phase B fault in Zone 3.

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- 7.13.14 Verify that the static switch “Trips/Opens” first, followed by breakers CB31, CB41 and CB51 clearing the fault. Gen-set A1 & A2 will shut down and breaker K32 should “Open” under PLC control, removing the fault of the Overload Load Bank.
- 7.13.15 Verify power flow change of 0kW at Meter 2 and 40kW at Meter 1 to Load Bank 6.
- 7.13.16 Verify in the DAS Database that:
 - 7.13.16.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.
 - 7.13.16.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.
- 7.13.17 Remove remaining load from the Microgrid Test Bed, “STOP” the static switch, and re-close breakers CB31, CB41 and CB51 to complete this fault test event.

7.14 **Zone 4 A-to-B Phase Fault, Gen-set (A1+A2) & Utility Connected Performance Goal** - Test a phase-to-phase fault condition in Zone 4 with Gen-sets A1 and A2 operating in-parallel with the utility grid to verify negative-sequence, I^2t protection or residual over-current protection.

- 7.14.1 Perform the Microgrid Test Bed Lockout/Tagout Procedure, described in Section 4.7.
- 7.14.2 Remove the Overload Load Bank portable cable/plug from the exterior receptacle and physically remove the portable overload cabling inside Cabinet 3a.
- 7.14.3 Setup the Overload Load Bank for a phase-to-phase fault (overload) between A and B phases of 84kW and connect the portable cable/plug into the exterior receptacle of Cabinet 5a
- 7.14.4 Install/physically connect the portable overload cabling inside Cabinet 5 from the outlet receptacle to A and B phases (i.e., connecting and tightening the bolted connections).
- 7.14.5 Reverse the Microgrid Test Bed Lockout/Tagout Procedure.

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- 7.14.6 Verify CB43 is “Closed” along with the circuit breakers to the Load Banks, manually “ARM” the key switch in the cabinet and close the entry doors to Cabinet 5.
- 7.14.7 Set Gen-set A1 & A2 to the following set-points:
Gen-set A1 & A2 = Unit Power Control Mode
Output Power Command = 20 kW each
MG Power/Frequency Droop= -0.0833 Hz/kW
MG Voltage Command= 277 V.
- 7.14.8 Using EMS, give a “Reset” command to clear all faults and events.
- 7.14.9 Once all events and alarms are cleared, “Start” the Gen-sets.
- 7.14.10 Once the Gen-sets are running and on-line, select loads on Load Bank 3, Load Bank 4 and Load Bank 6 to 40kW.
- 7.14.11 Use EMS to put the static switch in “Start” mode. Verify synchronized closing of the static switch.
- 7.14.12 After the synchronized closing of the static switch, the Microgrid Test Bed is connected to the utility grid with 40kW at Meter 2 and 80kW at Meter 1.
- 7.14.13 Using the DAS Load Control program, set the duration of the fault (overload) to 10 seconds, set the software to “ARM” and initiate a Phase A-to-Phase B fault in Zone 4.
- 7.14.14 Verify that the static switch “Trips/Opens” first, followed by breakers CB31, CB41 and CB51 clearing the fault. Gen-set A1 & A2 will shut down and breaker K42 should “Open” under PLC control, removing the fault of the Overload Load Bank.
- 7.14.15 Verify power flow change of 0kW at Meter 2 and 40kW at Meter 1 to Load Bank 6.
- 7.14.16 Verify in the DAS Database that:
 - 7.14.16.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.
 - 7.14.16.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.

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7.14.17 Remove remaining load from the Microgrid Test Bed, “STOP” the static switch, and re-close breakers CB31, CB41 and CB51 to complete this fault test event.

7.15 **Zone 2 A-to-B Phase Fault, Gen-set (A1+B1) & Utility Connected Performance Goal** - Test a phase-to-phase fault condition in Zone 2 with Gen-sets A1 and B1 operating in-parallel with the utility grid to verify negative-sequence, I^2t protection or residual over-current protection

7.15.1 Perform the Microgrid Test Bed Lockout/Tagout Procedure, described in Section 4.7.

7.15.2 Remove the Overload Load Bank portable cable/plug from the exterior receptacle and physically remove the portable overload cabling inside Cabinet 5a.

7.15.3 Setup the Overload Load Bank for a phase-to-phase fault (overload) between A and B phases of 84kW and connect the portable cable/plug into the exterior receptacle of Cabinet 2d.

7.15.4 Install/physically connect the portable overload cabling inside Cabinet 2d from the outlet receptacle to A and B phases (i.e., connecting and tightening the bolted connections).

7.15.5 Reverse the Microgrid Test Bed Lockout/Tagout Procedure.

7.15.6 Verify CB31, CB41, CB51, and K22 are “Closed” along with the circuit breakers to the Load Banks, manually “ARM” the key switch in the cabinet and close the entry doors to Cabinet 2d.

7.15.7 Set Gen-set A1 & B1 to the following set-points:

Gen-set A1 & A2 = Unit Power Control Mode
Output Power Command = 20 kW each
MG Power/Frequency Droop= -0.0833 Hz/kW
MG Voltage Command= 277 V.

7.15.8 Using EMS, give a “Reset” command to clear all faults and events.

7.15.9 Once all events and alarms are cleared, “Start” the Gen-sets.

7.15.10 Once the Gen-sets are running and on-line, select loads on Load Bank 3, Load Bank 5 and Load Bank 6 to 40kW.

7.15.11 Use EMS to put the static switch in “Start” mode. Verify synchronized closing of the static switch.

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- 7.15.12 After the synchronized closing of the static switch, the Microgrid Test Bed is connected to the utility grid with 40kW at Meter 2 and 80kW at Meter 1.
- 7.15.13 Using the DAS Load Control program, set the duration of the fault (overload) to 10 seconds, set the software to “ARM” and initiate a Phase A-to-Phase B fault in Zone 2.
- 7.15.14 Verify that the static switch “Trips/Opens” first, followed by breakers CB31, CB41 and CB51 clearing the fault. Gen-set A1 & B1 will shut down and breaker K22 should “Open” under PLC control, removing the fault of the Overload Load Bank.
- 7.15.15 Verify power flow change of 0kW at Meter 2 and 40kW at Meter 1 to Load Bank 6.
- 7.15.16 Verify in the DAS Database that:
 - 7.15.16.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.
 - 7.15.16.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.
- 7.15.17 Remove remaining load from the Microgrid Test Bed, “STOP” the static switch, and re-close breakers CB31, CB41 and CB51 to complete this fault test event.

7.16 **Zone 5 A-to-B Phase Fault, Gen-set (A1+B1) & Utility Connected Performance Goal** - Test a phase-to-phase fault condition in Zone 5 with Gen-sets A1 and B1 operating in-parallel with the utility grid to verify negative-sequence, I^2t protection or residual over-current protection.

- 7.16.1 Perform the Microgrid Test Bed Lockout/Tagout Procedure, described in Section 4.7.
- 7.16.2 Remove the Overload Load Bank portable cable/plug from the exterior receptacle and physically remove the portable overload cabling inside Cabinet 2d.
- 7.16.3 Setup the Overload Load Bank for a phase-to-phase fault (overload) between A and B phases of 84kW and connect the portable cable/plug into the exterior receptacle of Cabinet 7a.

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- 7.16.4 Install/physically connect the portable overload cabling inside Cabinet 7 from the outlet receptacle to A and B phases (i.e., connecting and tightening the bolted connections).
- 7.16.5 Reverse the Microgrid Test Bed Lockout/Tagout Procedure.
- 7.16.6 Verify CB53 is “Closed” along with the circuit breakers to the Load Banks, manually “ARM” the key switch in the cabinet and close the entry doors to Cabinet 7.
- 7.16.7 Set Gen-set A1 & B1 to the following set-points:
Gen-set A1 & A2 = Unit Power Control Mode
Output Power Command = 20 kW each
MG Power/Frequency Droop= -0.0833 Hz/kW
MG Voltage Command= 277 V.
- 7.16.8 Using EMS, give a “Reset” command to clear all faults and events.
- 7.16.9 Once all events and alarms are cleared, “Start” the Gen-sets.
- 7.16.10 Once the Gen-sets are running and on-line, select loads on Load Bank 3, Load Bank 5 and Load Bank 6 to 40kW.
- 7.16.11 Use EMS to put the static switch in “Start” mode. Verify synchronized closing of the static switch.
- 7.16.12 After the synchronized closing of the static switch, the Microgrid Test Bed is connected to the utility grid with 40kW at Meter 2 and 80kW at Meter 1.
- 7.16.13 Using the DAS Load Control program, set the duration of the fault (overload) to 10 seconds, set the software to “ARM” and initiate a Phase A-to-Phase B fault in Zone 5.
- 7.16.14 Verify that the static switch “Trips/Opens” first, followed by breakers CB31, CB41 and CB51 clearing the fault. Gen-set A1 & B1 will shut down and breaker K52 should “Open” under PLC control, removing the fault of the Overload Load Bank. (Note, due to the delta-wye transformer (T51) the zero-sequence and negative-sequence detection is less sensitive to faults in Zone 5.)
- 7.16.15 Verify power flow change of 0kW at Meter 2 and 40kW at Meter 1 to Load Bank 6.
- 7.16.16 Verify in the DAS Database that:

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- 7.16.16.1 The fault event waveforms of phase currents and voltages at all Relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, as well as the relay element that caused the “TRIP” with trip times for each relay relative to when the fault was applied.
- 7.16.16.2 The waveform and RMS Meter data were recorded. Note the above collection of all data and waveforms will take approximately 30 minutes to arrive.
- 7.16.17 Remove remaining load from the Microgrid Test Bed, “STOP” the static switch, and re-close breakers CB31, CB41 and CB51 to complete this fault test event.

8.0 Procedure – Reduced System Tests

Objective: The tests described in Section 8 are designed to ensure that the Gen-set inverter controls are working correctly. This includes unit control, feeder control, and mixed power controls, in conjunction with limit controls and synchronized closing of the static switch. These tests are based on the Tecogen / Youtility factory acceptance testing.

Measurement

- Sources – Injected power (kW), reactive load (kVAr), frequency (freq), and voltage (V) for each Gen-set (i.e., A1p, A2p and B1p).
- Zone input power flow into Zones 3 (A1z), 4 (A2z), 5 (B1z) and 6.
- Loads - Voltage at Load Bank 3 (L3), 4 (L4), 5 (L5), and 6 (L6).
- Static Switch (SS) - Power (kW) and current (I) through the static switch.
- Static Switch Control Signal: Forced “OPEN” and release to allow self synchronization.
- Voltage (V) and frequency (Freq) difference across the static switch.

Performance Goal – Expect to observe smooth transitions of the Gen-sets response to different step conditions (i.e., static switch “OPEN”/ “CLOSE” and load steps).

8.1 Initial Voltage Regulation Test – Single Zone, Islanded With Gen-set A1

Performance Goal – Verify smooth transitions of Gen-set A1 response to different step conditions of load in Load Bank 3 with voltage set point

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changes ranging from +5% to -5%. Repeat tests with Gen-set A2 in Load Bank 4, and then Gen-set B1 in Load Bank 5.

- 8.1.1 Verify the utility's CB1 breaker is "Closed" and the Microgrid Test Bed is energized with nominal voltages indicated on all three phases at Meter 1.
- 8.1.2 During the next sequence of tests, verify in the "DAS Database" file that when the test was performed, the event waveforms at all relay locations (i.e., Relays 2, 3, 4 & 5) were recorded, along with the test event times when the event was initiated.
- 8.1.3 Maintain the weak grid connection at L11 during this sequence of tests with the static switch "Open", all zone and load bank circuit breakers are "Closed", Gen-sets A1, A2 and B1 set for injection power control, and all load banks initially set at zero load.
- 8.1.4 Start Gen-set A1 in Zone 3 and then bring Load Bank 3 up to 20kW, balanced load, verify during this event that the voltage magnitude remains unchanged with minimum transients.
- 8.1.5 Verify in the DAS Database that the event waveforms of phase currents and voltages, plus RMS Meter data were recorded at all locations when the event was applied.
- 8.1.6 Apply step change of load event in Load Bank 3 from 20kW to 40kW, balanced load and observe the voltage magnitude remains unchanged with minimum transients.
- 8.1.7 Verify in the DAS Database that the event waveforms of phase currents and voltages, plus RMS Meter data were recorded at all locations when the event was applied.
- 8.1.8 Apply another step change of load event in Load Bank 3 from 40kW to 60kW, balanced load, and observe the voltage magnitude remains unchanged with minimum transients.
- 8.1.9 Verify in the DAS Database that the event waveforms of phase currents and voltages, plus RMS Meter data were recorded at all locations when the event was applied.

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- 8.1.10 Change the voltage set point from nominal to +5%. Then, repeat steps 8.1.4 through 8.1.9, and observe stable voltage control. Verify that the event waveforms of phase currents and voltages, plus RMS Meter data were recorded.
- 8.1.11 Change the voltage set point from +5% to -5%. Then, repeat steps 8.1.4 through 8.1.9, and observe stable voltage control. Verify that the event waveforms of phase currents and voltages, plus RMS Meter data were recorded
- 8.1.12 Reduce Load Bank 3 to zero and shutdown Gen-set A1.
- 8.1.13 Repeat steps 8.1.4, through 8.1.11 for Zone 4, using Load Bank 4 and Gen-set A2.
- 8.1.14 Reduce Load Bank 4 to zero and shutdown Gen-set A2.
- 8.1.15 Repeat steps 8.1.4, through 8.1.11 for Zone 5, using Load Bank 5 and Gen-set B1.
- 8.1.16 Reduce Load Bank 5 to zero and shutdown Gen-set B1.

8.2 **Open Static Switch Test, Check P = 0 Limit, Gen-set A1**

Performance Goal – Verify smooth transitions of Gen-sets A1 and A2 response to different step conditions (i.e., static switch “OPEN”/ “CLOSE”) with the unit power limit of Gen-set A1 equal to zero.

- 8.2.1 Maintain the weak grid connection at L11 during this sequence of tests with the static switch “Closed”, all zone and load bank circuit breakers are “Closed”, and Gen-sets A1, A2 and B1 set for injection power control.
- 8.2.2 Set balanced load in Load Banks 3, 4 & 6 to the kW values in the **Start** column. Then, start Gen-sets A1 and A2 in unit control mode with the settings indicated in **Start** column.

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Test Event - Open Static Switch				
	Mode	Start	Event	End
A1 _p	Unit	5kW		0.0kW
A2 _p	Unit	55kW		40kW
B1 _p		Off		Off
Freq.		~60Hz		~60.12
L3		20kW		20kW
L4		20kW		20kW
L5		0		
L6		20kW		20kW
SS	CLOSED	-20kW	OPEN	0.0kW
Grid		0		20kW
Let SS to Re-close				

- 8.2.3 Allow a few minutes for the Gen-sets to warm up. When the system is in steady state condition, force “Open” static switch control signal.
- 8.2.4 Verify that the Gen-set and load conditions are similar to the values in the **End** column.
- 8.2.5 Verify in the “DAS Database” file that at the time when this test was performed, that the test event data and waveforms of phase currents and voltages at affected locations were recorded in the DAS, along with the test event date/time when the event was initiated.
- 8.2.6 Release the static switch “Open” condition and allow self synchronization of the static switch to “Re-close”.
- 8.2.7 Verify in the “DAS Database” file that at the time when this synchronization event was performed, that the event data and waveforms of phase currents and voltages at affected locations were recorded in the DAS, along with the test event date/time when the event was initiated.
- 8.2.8 Verify that system conditions returned to the values listed in the **Start** column.
- 8.2.9 Shutdown Gen-sets A1 & A2 and reduce load in Load Banks 3, 4, & 6 to zero.

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- 8.3 **Open Static Switch Test, Check P = 60kW Limit, Gen-set A2**
Performance Goal – Verify smooth transitions of Gen-sets A1 and A2 response to different step conditions (i.e., static switch “OPEN”/ “CLOSE”) with the unit power limit of Gen-set A2 equal to 60kW.

- 8.3.1 Maintain the weak grid connection at L11 during this sequence of tests with the static switch “Closed”, all zone and load bank circuit breakers are “Closed” and Gen-sets A1, A2 and B1 set for injection power control.
- 8.3.2 Set balanced load in Load Banks 3 & 4 to the kW values in the **Start** column. Then, start Gen-sets A1 and A2 in unit control mode with the settings indicated in **Start** column.

Event Open SS				
	Mode	Start	Event	End
A1 _P	Unit	5kW		40kW
A2 _P	Unit	55kW		60kW
B1 _P		Off		Off
Freq		~60Hz		~59.72
L3		60kW		60kW
L4		40kW		40kW
L5		0		0
L6		0		0
SS	CLOSED	40kW	OPEN	0kW
Grid		40kW		0kW
Let SS re-close				

- 8.3.3 Allow a few minutes for the Gen-sets to warm up. When the system is in steady state condition, force “Open” static switch control signal.
- 8.3.4 Verify that the Gen-set and load conditions are similar to the values in the **End** column (i.e., Gen-set A1 power increases from 5kW to 40kW and Gen-set A2 power increases from 55kW to 60kW).
- 8.3.5 Verify in the “DAS Database” file that at the time when this test was performed, that the test event data and waveforms of phase currents and voltages at affected locations were recorded in the DAS, along with the test event date/time when the event was

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initiated.

- 8.3.6 Release the static switch “Open” condition and allow self synchronization of the static switch to “Re-close”.
- 8.3.7 Verify in the “DAS Database” file that at the time when this synchronization event was performed, that the event data and waveforms of phase currents and voltages at affected locations were recorded in the DAS, along with the test event date/time when the event was initiated.
- 8.3.8 Verify that system conditions return to the values listed in the **Start** column.
- 8.3.9 Shutdown Gen-sets A1 & A2 and reduce load in Load Banks 3 & 4 to zero.

8.4 Test Island Operation, Unbalanced Load

Performance Goal –Verify smooth transitions of Gen-sets A1 and A2 response to different step conditions (i.e., static switch “OPEN”/ “CLOSE”) with an un-balanced load condition in Zone 3.

- 8.4.1 During this sequence of tests, maintain the static switch “Open”, all zone and load bank circuit breakers are “Closed”, and Gen-sets A1, A2 and B1 set for injection power control.
- 8.4.2 Start Gen-sets A1 and A2 in unit control mode with the settings indicated in **Start** column. Then, set balanced load in Load Bank 3 to the kW value in the **Start** column.

Reduce A-Phase Load in Load Bank 3				
	Mode	Start	Event	End
A1 _p	Unit	15kW		~2.5kW
A2 _p	Unit	45kW		~37.5kW
B1 _p		Off		Off
Freq		~60Hz		~60.09
L3		60kW	A-phase = 0kW	40kW
L4		0kW		0kW
L5		0kW		0kW
L6		0kW		0kW
SS	OPEN	0kW		0kW
Grid		0kW		0kW
Should be no current in phase a				

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8.4.3 Allow a few minutes for the Gen-sets to warm up. When the system is in steady state condition, reduce A-phase load in Load Bank 3 from 20kW to 0kW.

8.4.4 Verify that there is zero kW (approximate) in Phase A, and that Gen-set and load conditions are similar to the values in the **End** column.

8.4.5 Verify in the “DAS Database” file that at the time when this test was performed, that the test event data and waveforms of phase currents and voltages at affected locations were recorded in the DAS, along with the test event date/time when the event was initiated.

8.4.6 Shutdown Gen-sets A1 & A2 and reduce load in Load Banks 3 to zero.

8.5 **Mixed Mode Operation Test – Feeder A, Gen-set A1 to 60kW Maximum**

Performance Goal –Verify smooth transitions of Gen-sets, A1 in Zone operation mode with a 60kW limit and A2 in Unit operation mode, during a load step change in Load Bank 3.

8.5.1 Maintain the weak grid connection at L11 during this sequence of tests with the static switch “Closed”, all zone and load bank circuit breakers are “Closed”, and Gen-sets A1, A2 and B1 set for injection power control.

8.5.2 Start Gen-sets A1 in zone control mode and A2 in unit control mode with the settings indicated in **Start** column. Then, set balanced load in Load Banks 3 & 4 to the kW values in the **Start** column.

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Step load				
	Mode	Start	Event	End
A1 _z	Zone	54kW		54kW
A1 _p	Injected Power	10kW		60kW Max
A2 _p	Unit	6kW		6kW
B1 _p		Off		Off
Freq		~60Hz		~60Hz
L3		35kW	Add 50kW	85kW
L4		35kW		35kW
L5		0		0
L6		0		0
SS	CLOSED	54kW		54kW
Grid		54kW		54kW
SS stays Closed				

- 8.5.3 Allow a few minutes for the Gen-sets to warm up. When the system is in steady state condition, increase balanced three phase load in Load Bank 3 from 35kW to 85kW.
- 8.5.4 Verify that Gen-set and load conditions are similar to the values in the **End** column (i.e., injected power from Gen-set A1 increases from 10kW to 60kW with the Zone power in Feeder A maintained at 54kW).
- 8.5.5 Verify in the “DAS Database” file that at the time when this test was performed, that the test event data and waveforms of phase currents and voltages at affected locations were recorded in the DAS, along with the test event date/time when the event was initiated.
- 8.5.6 Shutdown Gen-sets A1 & A2 and reduce load in Load Banks 3 & 4 to zero.

8.6 Mixed Mode Operation Test – Feeder A, Automatic Reset of Zone Level Set-Point

Performance Goal –Verify smooth transitions of Gen-sets, A1 in Zone operation mode with an automatic reset of the set point and A2 in Unit operation mode, during a load step change in Load Bank 4.

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- 8.6.1 Maintain the weak grid connection at L11 during this sequence of tests with the static switch “Closed”, all zone and load bank circuit breakers are “Closed”, and Gen-sets A1, A2 and B1 set for injection power control.
- 8.6.2 Start Gen-sets A1 in zone control mode and A2 in unit control mode with the settings indicated in **Start** column. Then, set balanced load in Load Banks 3 & 4 to the kW values in the **Start** column.

Step load				
	Mode	Start	Event	End
A1z	Zone	55kW		65kW
A1p	Injected Power	50kW		60kW, A1 at Max
A2p	Unit	5kW		5kW
B1p		Off		Off
Freq		~60Hz		~60Hz
L3		75kW		75kW
L4		35kW	Add 20kW	55kW
L5		0		0
L6		0		0
SS	CLOSED	55kW		65kW
Grid		55kW		65kW
SS stays Closed				

- 8.6.3 Allow a few minutes for the Gen-sets to warm up. When the system is in steady state condition, increase balanced three phase load in Load Bank 4 from 35kW to 55kW.
- 8.6.4 Verify that Gen-set and load conditions are similar to the values in the **End** column (i.e., load change forces the injected power of Gen-set A1 to exceed its maximum and the system should automatically reset its Zone power level set-point from 55kW to 65kW to hold Gen-set A1 to 60kW with power from the grid increased from 55kW to 65kW).
- 8.6.5 Verify in the “DAS Database” file that at the time when this test was performed, that the test event data and waveforms of phase currents and voltages at affected locations were recorded in the

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DAS, along with the test event date/time when the event was initiated.

8.6.6 Shutdown Gen-sets A1 & A2 and reduce load in Load Banks 3 & 4 to zero.

8.7 **Mixed Mode Operation Test – Feeder A, Zone Power Change Performance Goal** –Verify smooth transitions of Gen-sets, A1 in Zone operation mode and A2 in Unit operation mode, with a change of zone power in Feeder A.

8.7.1 Maintain the weak grid connection at L11 during this sequence of tests with the static switch “Closed”, all zone and load bank circuit breakers are “Closed”, and Gen-sets A1, A2 and B1 set for injection power control.

8.7.2 Start Gen-sets A1 in zone control mode and A2 in unit control mode with the settings indicated in **Start** column. Then, set a balanced load in Load Banks 3 & 4 to the kW values in the **Start** column.

Large Zone Set to Pickup System				
	Mode	Start	Event	End
A1z	Zone	54kW	Add 56kW	110kW
A1p	Injected Power	60kW A1 at max		4kW
A2p	Unit	6kW		6kW
B1p		Off		Off
Freq		~60Hz		~60Hz
L3		85kW		85kW
L4		35kW		35kW
L5		0		0
L6		0		0
SS	CLOSED	54kW		110kW
Grid		54kW		110kW
EMS : Zone A1 from 54kW to 110 kW				

8.7.3 Allow a few minutes for the Gen-sets to warm up. When the system is in steady state condition, use the EMS to change/increase the Zone power level in Feeder A from 54kW to 110kW.

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- 8.7.4 Verify that Gen-set and load conditions are similar to the values in the **End** column (i.e., the Zone power change in Feeder A forces Gen-set A1 to reduce its injected power from 60kW to 4kW and power from the grid increased from 54kW to 110kW).
- 8.7.5 Verify in the “DAS Database” file that at the time when this test was performed, that the test event data and waveforms of phase currents and voltages at affected locations were recorded in the DAS, along with the test event date/time when the event was initiated.
- 8.7.6 Shutdown Gen-sets A1 & A2 and reduce load in Load Banks 3 & 4 to zero.

8.8 **Mixed Mode Operation Test – Feeder A, Zone Power Change When Islanded**

Performance Goal –Verify smooth transitions of Gen-sets, A1 in Zone operation mode and A2 in Unit operation mode, with a static switch operation and a change of zone power in Feeder A when islanded.

- 8.8.1 Maintain the weak grid connection at L11 during this sequence of tests with the static switch “Closed”, all zone and load bank circuit breakers are “Closed”, and Gen-sets A1, A2 and B1 set for injection power control.
- 8.8.2 Start Gen-sets A1 in zone control mode and A2 in unit control mode with the settings indicated in **Start** column. Then, set a balanced load in Load Banks 3 & 4 to the kW values in the **Start** column.

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Open SS				
	Mode	Start	Event	End
A1z	Zone	50kW		0kW
A1p	Injected Power	14kW		~18kW
A2p	Unit	6kW		~52kW
B1p		Off		Off
Freq		~60Hz		~59.6Hz
L3		35kW		35kW
L4		35kW		35kW
L5		0		0
L6		0		0
SS	CLOSED	50kW	OPEN	0kW
Grid		50kW		0kW
Allow SS to Re-close				

- 8.8.3 Allow a few minutes for the Gen-sets to warm up. When the system is in steady state condition, force “Open” static switch control signal.
- 8.8.4 Verify that the Gen-set and load conditions are similar to the values in the **End** column (i.e., Zone power in Feeder A decreases from 50kW to 0kW, Gen-set A1 power increases from 14kW to about 18kW, Gen-set A2 power increases from 6kW to about 52kW, frequency decreases by about 0.4Hz, and power from the grid decreases from 50kW to zero).
- 8.8.5 Verify in the “DAS Database” file that at the time when this test was performed, that the test event data and waveforms of phase currents and voltages at affected locations were recorded in the DAS, along with the test event date/time when the event was initiated.
- 8.8.6 Release the static switch “Open” condition and allow self synchronization of the static switch to “Re-close”.
- 8.8.7 Verify in the “DAS Database” file that at the time when this synchronization event was performed, that the event data and waveforms of phase currents and voltages at affected locations

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were recorded in the DAS, along with the test event date/time when the event was initiated.

- 8.8.8 Verify that system conditions returned to the values listed in the **Start** column.
- 8.8.9 Shutdown Gen-sets A1 & A2 and reduce load in Load Banks 3 & 4 to zero.

8.9 **Mixed Mode Operation Test - Feeder A, When Islanded Automatic Reset of Zone Level Set-point, Both Gen-sets P = 60kW Maximum Performance Goal** –Verify smooth transitions of Gen-sets, A1 in Zone operation mode with automatic reset of set point and A2 in Unit operation mode, with a static switch operation and a change of zone power in Feeder A when islanded.

- 8.9.1 Maintain the weak grid connection at L11 during this sequence of tests with the static switch “Closed”, all zone and load bank circuit breakers are “Closed”, and Gen-sets A1, A2 and B1 set for injection power control.
- 8.9.2 Start Gen-sets A1 in zone control mode and A2 in unit control mode with the settings indicated in **Start** column. Then, set a balanced load in Load Banks 3 & 4 to the kW values in the **Start** column.

Open SS, Test Gen-set P _{max.}				
	Mode	Start	Event	End
A1z	Zone	54kW		0kW
A1p	Injected Power	60kW		60kW A1 at Max.
A2p	Unit	6kW		60kW A2 at Max.
B1p		Off		Off
Freq		~60Hz		~59.5Hz
L3		60kW		60kW
L4		60kW		60kW
L5		0		0
L6		0		0
SS	CLOSED	54kW	OPEN	0kW
Grid		54kW		0kW
Allow SS to Re-close				

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- 8.9.3 Allow a few minutes for the Gen-sets to warm up. When the system is in steady state condition, force “Open” static switch control signal.
- 8.9.4 Verify that the Gen-set and load conditions are similar to the values in the **End** column (i.e., Zone power in Feeder A decreases from 50kW to 0kW, Gen-set A1 power remains at 60kW, Gen-set A2 power increases from 6kW to about 60kW, frequency decreases by about 0.5 Hz, and power from the grid decreases from 50kW to zero).
- 8.9.5 Verify in the “DAS Database” file that at the time when this test was performed, that the test event data and waveforms of phase currents and voltages at affected locations were recorded in the DAS, along with the test event date/time when the event was initiated.
- 8.9.6 Release the static switch “Open” condition and allow self synchronization of the static switch to “Re-close”.
- 8.9.7 Verify in the “DAS Database” file that at the time when this synchronization event was performed, that the event data and waveforms of phase currents and voltages at affected locations were recorded in the DAS, along with the test event date/time when the event was initiated.
- 8.9.8 Verify that system conditions returned to the values listed in the **Start** column.
- 8.9.9 Shutdown Gen-sets A1 & A2 and reduce load in Load Banks 3 & 4 to zero.
- 8.10 **Two Sources in Zone Control - Separate Feeders, When Islanded Automatic Reset of Zone Level Set-point, New Zones Sum Equal Zero Performance Goal** –Verify smooth transitions of Gen-sets, A1 and B1 in Zone operation mode, with a static switch operation and a change of zone power in Feeder A and Feeder B when islanded.
 - 8.10.1 Maintain the weak grid connection at L11 during this sequence of tests with the static switch “Closed”, all zone and load bank circuit breakers are “Closed”, and Gen-sets A1, A2 and B1 set for injection power control.

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- 8.10.2 Start Gen-sets A1 and B1 in zone control mode with the settings indicated in **Start** column. Then, set a balanced load in Load Banks 3 & 5 to the kW values in the **Start** column.

Two Zone Control Test: Separate Event Open SS				
	Mode	Start	Event	End
A1z	Zone	40kW		10kW
A1p	Injected Power	0kW		30kW
A2p		Off		Off
B1z	Zone	10kW		-10Kw
B1p	Injected Power	40kW		60kW B1 at Max.
Freq		~60Hz		~59.76
L3		40kW		40kW
L4		0		0
L5		50kW		50kW
L6		0		0
SS	CLOSED	50kW	OPEN	0.0kW
Grid		50kW		0.0kW
Let SS Re-close				

- 8.10.3 Allow a few minutes for the Gen-sets to warm up. When the system is in steady state condition, force “Open” static switch control signal.
- 8.10.4 Verify that the Gen-set and load conditions are similar to the values in the **End** column (i.e., Zone power in Feeder A decreases from 40kW to 10kW and Gen-set A1 injected power increases from 0kW to 30kW; Zone power in Feeder B decreases from +10kW to -10kW and Gen-set B1 injected power increases from 40W to about 60kW, frequency decreases by about 0.25 Hz, and power from the grid decreases from 50kW to zero). Also, verify when the system islands, the sum of the new zone settings equal zero (i.e., -10kW +10kW).
- 8.10.5 Verify in the “DAS Database” file that at the time when this test was performed, that the test event data and waveforms of phase currents and voltages at affected locations were recorded in the

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DAS, along with test event date/time when the event was initiated.

- 8.10.6 Release the static switch “Open” condition and allow self synchronization of the static switch to “Re-close”.
- 8.10.7 Verify in the “DAS Database” file that at the time when this synchronization event was performed, that the event data and waveforms of phase currents and voltages at affected locations were recorded in the DAS, along with the test event date/time when the event was initiated.
- 8.10.8 Verify that system conditions returned to the values listed in the **Start** column.
- 8.10.9 Shutdown Gen-sets A1 & A2 and reduce load in Load Banks 3 & 4 to zero

8.11 Two Sources in Zone Control - Separate Feeders, When Islanded Automatic Reset of Zone Level Set-points

Performance Goal –Verify smooth transitions of Gen-sets, A1 and B1 in Zone operation mode and both having automatic reset of set points, with a static switch operation and a change of zone power in Feeder A and Feeder B when islanded.

- 8.11.1 Maintain the weak grid connection at L11 during this sequence of tests with the static switch “Closed”, all zone and load bank circuit breakers are “Closed”, and Gen-sets A1, A2 and B1 set for injection power control.
- 8.11.2 Start Gen-sets A1 and B1 in zone control mode with the settings indicated in **Start** column. Then, set a balanced load in Load Banks 3, 5, & 6 to the kW values in the **Start** column.

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Two-Zones: Event Open SS				
	Mode	Start	Event	End
A1z	Zone	-30kW		-25kW
A1p	Injected Power	50kW		45kW
A2p		Off		Off
B1z	Zone	20kW		25Kw
B1p	Injected Power	20kW		15kW
Freq		~60Hz		~60.04Hz
L3		20kW		20kW
L4		0		0
L5		40kW		40kW
L6		20kW		20kW
SS	CLOSED	-10kW	OPEN	0.0kW
Grid		10kW		20kW
Let SS Re-close				

- 8.11.3 Allow a few minutes for the Gen-sets to warm up. When the system is in steady state condition, force “Open” static switch control signal.
- 8.11.4 Verify that the Gen-set and load conditions are similar to the values in the **End** column (i.e., Zone power in Feeder A changes from -30kW to -25kW and Gen-set A1 injected power decreases from 50kW to 45kW; Zone power in Feeder B increases from +20kW to +25kW; and Gen-set B1 injected power decreases from 20W to 15kW, frequency increases by about 0.04 Hz, and power from the grid increases from 10kW to 20kW). Also, verify when the system islands, the automatic reset of the Zones with one Zone exporting power and the other Zone importing power. Note, at the start of this test 10kW of power is being exported through the Static Switch to Feeder C
- 8.11.5 Verify in the “DAS Database” file that at the time when this test was performed, that the test event data and waveforms of phase currents and voltages at affected locations were recorded in the

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DAS, along with test event date/time when the event was initiated.

- 8.11.6 Release the static switch “Open” condition and allow self synchronization of the static switch to “Re-close”.
- 8.11.7 Verify in the “DAS Database” file that at the time when this synchronization event was performed, that the event data and waveforms of phase currents and voltages at affected locations were recorded in the DAS, along with the test event date/time when the event was initiated.
- 8.11.8 Verify that system conditions returned to the values listed in the **Start** column.
- 8.11.9 Shutdown Gen-sets A1 & B1 and reduce load in Load Banks 3, 5, & 6 to zero.

8.12 Test Generator Black-Start Procedure

Objective: This test will check the manual procedure used to black-start the Microgrid Test Bed in the event of a lengthy utility outage occurs with the Gen-sets off-line.

Measurement – Record the transition of the Gen-set meters as they are started and brought on-line and as load banks are switched on-line. Note, the transition time between all events.

Performance Goal - Bring up the Microgrid Test Bed from a black-out condition without generation or protection trips.

- 8.12.1 Maintain the weak grid connection at L11 during this sequence of tests with the static switch “Closed”, all zone and load bank circuit breakers are “Closed” and all load banks initially set at zero load.
- 8.12.2 Begin with Gen-sets A1, A2 and B1 set for injection power control, off-line and shut down. Using the Walnut Breaker Control Program, “Open” CB1 to simulate a utility outage with the Microgrid de-energized, referred to as a black-out.
- 8.12.3 Using the EMS and DAS programs:
 - 8.12.3.1 Set a manual “Open” on the static switch.

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8.12.3.2 Using the DAS Load Control program, reduce load on Load Banks 3, 4 and 5 to zero.

8.12.3.3 Individually start Gen-set A1, Gen-set A2 and Gen-set B1; wait a few minutes (e.g., 3-4 minutes) to allow them to warm up and come on-line.

8.12.3.4 Using the DAS Load Control program, select the load in each Load Bank (i.e., 3, 4 & 5) to 27kW +j 13kVAr, and then switch the load on-line. The Microgrid is now manually islanded and supporting 90kVA of loads.

8.12.3.5 Remove the manual “Open” on the static switch.

8.12.4 Using the Walnut Breaker Control Program, “Close” circuit breaker CB1 to restore utility voltage and observe automatic reconnection (i.e., synchronization) after the IEEE 1547 restoration timer elapses, which is 300 seconds (recall utility outage creates an IEEE 1547 voltage event).

8.12.5 Verify in the DAS Database file that at the time when this synchronization event was performed, that the event data and waveforms of phase currents and voltages at affected locations were recorded in the DAS, along with test event date/time when the event was initiated.

8.12.6 Shutdown Gen-sets A1, A2, & B1 and reduce load in Load Banks 3, 4 & 5 to zero.

8.13 Test/Establish Generator Black-Start Capacity

Performance Goal – Determine the Black-start capacity of the microgrid by increasing the amount of load on the Microgrid Test Bed from a black-out condition without generation or protection trips.

8.13.1 Maintain the weak grid connection at L11 during this sequence of tests with the static switch “Closed”, all zone and load bank circuit breakers are “Closed” and all load banks initially set at zero load.

8.13.2 Begin with Gen-sets A1, A2 and B1 set for injection power control, off-line and shut down. Using the Walnut Breaker Control Program, “Open” CB1 to simulate a utility outage with the Microgrid de-energized, referred to as a black-out.

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8.13.3 Using the EMS and DAS programs:

- 8.13.3.1 Set a manual “Open” on the static switch.
- 8.13.3.2 Set the load in Load Bank 3 at 27kW +j 13kVAr, and verify that load bank circuit breaker CB33 is “Closed”.
- 8.13.3.3 Start Gen-set A1 with Load Bank 3 load connected when starting the generator wait a few minutes (e.g., 3-5 minutes) for the engine to warm up, than the inverter contactor will “Close” to serve load on-line.
- 8.13.3.4 Verify in the DAS Database file that at the time when the inverter contactor Closed, the test event data and waveforms of phase currents and voltages were recorded in the DAS, along with test event date/time when the event was initiated.
- 8.13.3.5 Shutdown Gen-set A1. Note, Gen-set A1 was manually islanded and supporting 30kVA of load.
- 8.13.3.6 Increase load in Load Bank 3 to 36kW +j 19.5VAr, and verify that load bank circuit breaker CB33 is “Closed”.
- 8.13.3.7 Start Gen-set A1 with Load Bank 3 load connected when starting the generator wait a few minutes (e.g., 3-5 minutes) for the engine to warm up, than the inverter contactor will “Close” to serve load on-line
- 8.13.3.8 Verify in the DAS Database file that at the time when the inverter contactor Closed, the test event data and waveforms of phase currents and voltages were recorded in the DAS, along with test event date/time when the event was initiated.
- 8.13.3.9 Shutdown Gen-set A1. Note, Gen-set A1 was manually islanded and supporting 40kVA of load.
- 8.13.3.10 Increase load in Load Bank 3 to 54kW +j 26VAr, and verify that load bank circuit breaker CB33 is “Closed”.

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- 8.13.3.11 Start Gen-set A1 with Load Bank 3 load connected when starting the generator wait a few minutes (e.g., 3-4 minutes) for the engine to warm up, than the inverter contactor will “Close” to serve load on-line.
- 8.13.3.12 Verify in the DAS Database file that at the time when the inverter contactor Closed, the test event data and waveforms of phase currents and voltages were recorded in the DAS, along with test event date/time when the event was initiated.
- 8.13.3.13 Shutdown Gen-set A1. Note, Gen-set A1 was manually islanded and supporting 60kVA of load.
- 8.13.3.14 If Gen-set A1 successfully islanded and supported 60kVA of load, increase load in Load Bank 3 to 63kW+j30.5kVAr, and verify that load bank circuit breaker CB33 is “Closed”.
- 8.13.3.15 Start Gen-set A1 with Load Bank 3 load connected when starting the generator wait a few minutes (e.g., 3-4 minutes) for the engine to warm up, than the inverter contactor will “Close” to serve load on-line.
- 8.13.3.16 Verify in the DAS Database file that at the time when the inverter contactor Closed, the test event data and waveforms of phase currents and voltages were recorded in the DAS, along with test event date/time when the event was initiated.
- 8.13.3.17 Shutdown Gen-set A1. Note, if successful, then Gen-set A1 manually islanded and supported 70kVA of load.

9.0 Procedure – Demonstration Tests of Control Power Flow

Objective - To demonstrate the flexibility of the Microgrid both grid connected and islanded for different loads, power flows and impact on the utility. First sequence of tests will include the weak grid inductors (i.e., L11) in the circuit.

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Second sequence of tests will repeat a select number of the most interesting results under strong grid conditions.

Measurements: Collect RMS data for V, I, kW, kVAr, and Freq for each flow change at the following points:

- Meter 1 – I, kW, kVAr for the utility connection
- Meter 2 - I, kW, kVAr and utility-side V and Freq
- Meter 3 - I, kW, and kVAr for Feeder A and Microgrid side V and Freq
- Meter A1p – I, kW, kVAr for Gen-set A1
- Load Meter 3 – Zone 3 load kW and kVAr
- Meter 4 – I, kW, kVAr for Zone 4
- Meter A2p – I, kW, kVAr for Gen-set A2
- Load Meter 4 – Zone 4 load kW and kVAr
- Meter 5 – I, kW, kVAr for Feeder B
- Meter B1p – I, kW, kVAr for Gen-set B1
- Load Meter 5 – Zone 5, Feeder B load kW and kVAr
- Load Meter 6 – Zone 6, Feeder C load kW and kVAr

In addition collect:

- V and I waveform data for unexpected events and for static switch transitions.
- Motor torque waveforms for all switch transitions.

Loading: Load on Feeder A & Feeder B must be less than 170 kW and Feeder C should be such that there is no power into the utility grid. All loads should include an approximate 0.9 power factor (pf), if possible. The motor load will be included as part of Zone 3.

9.1 Unit Control Mode, Weak Grid

Performance Goal – Verify and document power flow and Microgrid frequency changes when transitioning from utility connected to an islanded mode of operation. During each sequence of tests in Table 1, maintain a weak grid connection with L11 in the circuit and the static switch “Closed”; all zone and load bank circuit breakers “Closed”; Gen-sets A1, A2 and B1 set for Unit (injection power) control mode; and all load banks initially set at zero.

9.1.1 Each test event procedure begins with setting the load (i.e., balanced load) conditions as indicated in the Table, using the EMS with reactive load set at each Load Bank to achieve an